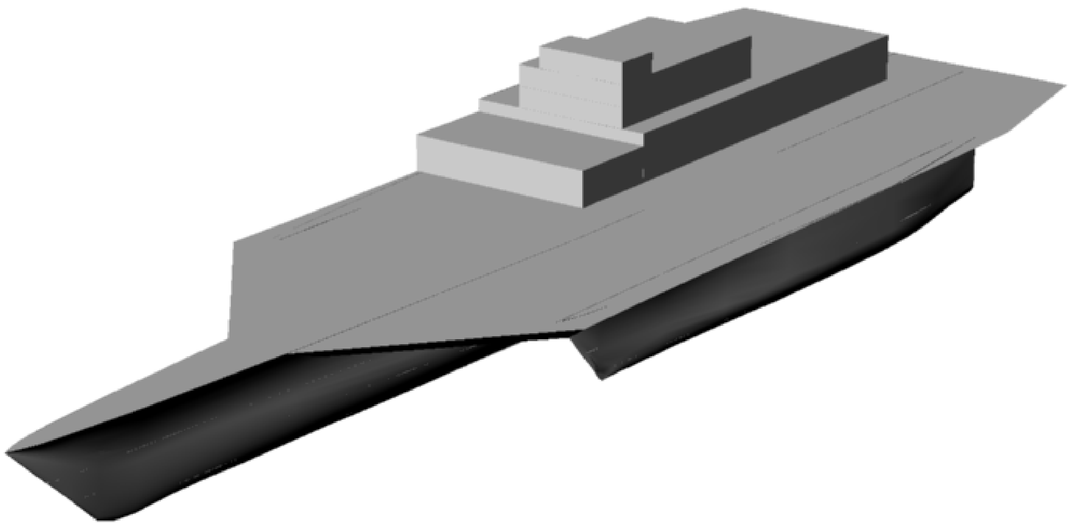
13.414 PROJECTS IN NEW CONSTRUCTION NAVAL SHIP DESIGN



LHA(R): AMPHIBIOUS ASSAULT SHIPS FOR THE 21ST CENTURY

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Executive Summary

Amphibious assault ships such as the current LHA and LHD classes are an essential element of the country's ability to exert influence anywhere in the world. The current amphibious assault ships represent the most capable amphibious ships in the world. The LHA 1 class ships are aging, however, with most reaching the end of their expected service lives between 2011 and 2015. It is not feasible to extend the service life of the LHA 1 class due to the rapid technological advances that have taken place during their lifetime. Most have already used their entire growth margin in areas such as combat systems and topside weights. The evolving combat systems and aircraft requirements will only exacerbate these matters. The best solution is to replace the LHA.

As the US faces a future with uncertain threats, it is necessary to field a flexible force. In order to make the amphibious forces flexible, selective offload capability must be considered. This allows Marines to access the equipment and vehicles they need for any given operation at any time. A second change that adds a great deal of flexibility is the addition of more ships. Currently, an Amphibious Ready Group (ARG) consists of three ships, an LHA or LHD, an LSD, and an LPD. Replacing the LHA with two ships has several advantages, ranging from increasing the selective offload capability of the ARG to optimally distributing assets among the ships. Most importantly, though, is the ability of the ARG to exert influence over a greater geographic area.

In this study, four different options were considered for the future ARG:

a. LPD 17, LSD 41, modified LHD 8 plus complement ship variants
b. LPD 17, LSD 41, two small LHD variants (2 ships with same hull)
c. LPD 17, LSD 41, two new design variants
d. LPD 17, LSD 41, single ship LHA(R) variants

After modeling a number of variants representing each option, an Overall Measure of Effectiveness (OMOE) and a total lifecycle cost was calculated. Analysis of these variants showed that the variants in Option (a) have a higher OMOE and a relatively lower cost than other options. This study now focuses on the complement ship to a modified LHD 8.

A comparison of hull forms, including catamarans, surface effect ships, hydrofoils, trimarans, monohulls, semi-planing monohulls, led to the selection of a trimaran, primarily for its ability to transport equipment at a high speed over a long range. In order to keep the size (and cost) of the ship down, the ship will not carry any landing craft. The nominal amphibious lift capacity of the trimaran complement ship is:

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1 Mission Need

1.1 Defense Policy and Guidance

The design philosophy for the LHA(R) is drawn from Joint Vision 2010 [1], which outlines the vision of a United States force that is "persuasive in peace, decisive in war, preeminent in any form of conflict" (p. 2). Additionally, the document addresses the need to "strengthen our military capabilities by taking advantage of improved technology" (p. 34). The Mission Need Statement (MNS) found in Appendix A guides the future amphibious assault ship design, research, development and acquisition program decisions, service and joint doctrine, and cooperative efforts with U.S. allies.

1.2 Threat

Since the end of the Cold War, the threats that the U.S. faces have changed dramatically. The fluid nature of today's geopolitical climate does not allow the U.S. to accurately predict where future threats will come from. The Quadrennial Defense Review Report dated 30 September 2001 [2] identifies the following trends that may give rise to important threats:

a. The geographic isolation of the U.S. no longer guarantees protection from a direct attack, as demonstrated by the September 11, 2001 events. Increased international travel makes the country more vulnerable to hostile attacks that originate within its borders. The threat of ballistic missile attacks is also increasing as more regional powers develop missiles with longer ranges.

b. The potential exists throughout the world for regional powers to develop military capabilities allowing them to threaten the stability of areas critical to U.S. interests. Many of these states are developing ballistic missile and chemical, biological and radiological weapons.

c. Many countries are suffering under weak and even failing governments. The inability of states to govern themselves gives rise to international threats such as drug trafficking and terrorism. Additionally, some of these states are unable to safeguard their military assets, which may fall into the hands of non-state actors.

d. Non-state actors, such as terrorists have proven that they have the capability to conduct devastating attacks on U.S. citizens. The proliferation of weapons of mass destruction leads to concerns that future terrorist attacks may be even more destructive.

e. The locations of future conflicts are unknown, due to the unpredictability of future threats. This prevents the U.S. from planning and preparing for a conflict in a well-defined region. Instead, the crisis will be unexpected, and could be in a remote location, presenting many operational challenges.

The anticipated threat environment that this Amphibious Assault Ship is expected to operate in is described in "Major Surface Ship Threat Assessment," ONI-TA-018-00, November 1999, and the DIA validated "Landing Platform Dock (LPD 17) System Threat Assessment," (STAR) ONI-TA-036-00, January 2000.

1.3 Current Capability Assessment

The current amphibious assault ships represent the most capable amphibious ships in existence. The LHA 1 class ships will reach the end on their expected service lives between 2011 and 2015. As the Navy and Marine Corps prepare for the future, a number of shortfalls in the current LHA 1 ships have been identified.

a. LHA 1 class ships are not compatible with the future Aviation Combat Element (ACE) envisioned by the Marine Corps.

b. Their designs do not meet current environmental, habitability and survivability standards.

c. The LHA design has no more growth margin in areas such as combat systems and topside weight.

d. The LHA design does not support evolving surface craft operations.

1.4 Mission Need

The MNS provides requirements for a new amphibious assault ship which must provide forward presence and power projection as an integral part of joint, interagency and multinational maritime expeditionary forces. It must embark, support and operate with the following elements for sustained periods, in transit to and during operations within an Amphibious Objective Area (AOA).

a. Naval amphibious tactical and administrative organizations for command, control and operations.

b. Elements of a landing force (personnel, vehicles, assault amphibians, cargo, ammunition and petroleum, oil and lubricants (POL)).

c. Landing craft (Landing Craft Air Cushion (LCAC) and conventional).

d. Aircraft (Short Takeoff Vertical Landing (STOVL) fixed-wing, rotary-wing, tiltrotor and Unmanned Aerial Vehicles (UAV)).

The ship will launch preloaded assault craft (amphibian vehicles and landing craft), tiltrotors, helicopters, UAVs, and fixed-wing (STOVL) aircraft in support of amphibious operations. The assault ship must have the ability to serve as the primary command and control platform to conduct the primary mission of the Amphibious Task Force, and it must be capable of embarking and operating with Joint, Interagency and Combined command and control staff functions.

The amphibious assault ship must be capable of supporting all aspects of the amphibious campaign, including responding to changing mission needs. It must be inherently flexible to support and conduct concurrent fixed-wing and rotary-wing/tiltrotor aircraft operations and simultaneous well deck and flight deck operations, day or night. It must also be capable of operating anywhere in the open ocean or littoral in a task force/group or independently commensurate with its self-defense capability over the full range of threat levels in peacetime, crisis and warfighting scenarios. Additionally, it must be capable of operating in a highly dynamic physical environment, which may be very data-sparse, and must therefore be capable of collecting, assimilating, and applying multi-source environmental data. Availability of forward land bases cannot be assumed.

1.5 Recommended Alternatives

Given the flexibility, mobility, presence and length of on-station time of a ship, as well as the low impact to host nations or allies, no other platform provides a more cost-effective approach to supporting the mission. At this time, there are not any known systems or programs deployed or in development or production by any of the other services or allied nations which address similar needs. Non-material alternatives, such as changes in doctrine or operational concepts, are not sufficient to meet the need. Material alternatives include:

a. A new ship design
b. Modifications of the LHD class.

2 Design Requirements and Plan

2.1 Required Operational Capabilities

The mission of the LHA(R) and the projected threat environment drive the selection of Required Operational Capabilities (ROCs) for the ship. OPNAVINST C3501.2H, Naval Warfare Mission Areas and Required Operational Capability/Projected Operational Environment Statements dated 02 November 1997 [3] gives a list and formal definition of standard ROCs. The major functions of the Navy, including sea control, power projection and strategic sealift are divided into several mission areas, such as Amphibious Warfare (AMW) or Mobility (MOB). Each mission area is further divided into operational capabilities, which can be broken into sub-operational capabilities. An example of an operational capability for the AMW mission area is:

AMW 5: Conduct landing craft or amphibious vehicle operations to support an amphibious assault.

A sub-operational capability of AMW 5 is:

AMW 5.5: Conduct Landing Craft Air Cushion (LCAC) operations.

The ROC mission areas necessary for the success of the LHA(R) appear in Table 1. Appendix B contains a more detailed list of the individual ROCs for the LHA(R).

Table 1. ROC Mission Areas

Mission Area		Brief Description
AAW	Anti-air Warfare	Self-defense/Support USMC AAW
AMW	Amphibious Warfare	Amphibious Assault
ASU	Antisurface Ship Warfare	Self-defense, Cooperative Engagement
ASW	Antisubmarine Warfare	Evasion
CCC	Command, Control and Communications	Communications, Data-links
C^2W	Command and Control Warfare	Electronic Warfare
FSO	Fleet Support Operations	Medical/Dental
INT	Intelligence	Surveillance/Reconnaissance
LOG	Logistics	Underway Replenishment
MIW	Mine Warfare	Mine Avoidance
MOB	Mobility	Maneuvering/Navigation

2.2 Concept of Operations

The Concept of Operations (CONOPS) for the LHA(R) is a general description of the envisioned employment of the ship and the embarked USMC assets. It serves as an extension of the MNS in determining the requirements for the ship.

2.2.1 Marine Corps Warfighting Concepts

The Concept of Operations for any amphibious ship is highly dependent on the Marine Corps warfighting concepts. The principal Marine Corps concepts affecting the LHA(R) are Operational Maneuver From the Sea (OMFTS) and Ship-to-Objective Maneuver (STOM). OMFTS calls for operational maneuver of forces to direct an attack against an enemy center of

gravity, or something essential to the enemy's warfighting ability. As the U.S. prepares to face the uncertain threats of the future, naval forces designed today must be able to adapt to new situations as they arise. In light of this uncertainty, OMFTS defines an approach, not a method, to expeditionary, littoral and amphibious warfare that "will provide naval forces with a solid foundation for future improvisation" [4].

The LHA(R) will operate with other amphibious ships as part of an Amphibious Task Force (ATF). The ATF must be able to "transport, project ashore, support, recover, and redeploy Marine Air-Ground Task Forces (MAGTFs)" [5]. The smallest form of a MAGTF is a Marine Expeditionary Unit (MEU), which is embarked on the ships of an Amphibious Ready Group (ARG). For the purposes of this report, an ARG consists of a "big-deck" amphibious assault ship such as an LHA or LHD, as well as an LSD and an LPD.

2.2.2 Historical Mission Analysis

While there is great uncertainty regarding the future threats that the LHA(R) will face, some insight can be drawn from historical trends in the operations of amphibious ships. During the 1990s, ships from various ARGs were involved in a wide variety of operations. These operations range from the multiple ARG wartime operations of Desert Storm to small, single-ship humanitarian missions [6]. Since the ARGs are designed primarily for wartime operations, Desert Storm missions are not included in this study. This study looks at peacetime operations only and attempts to determine any trends in ARG operations. Figure 1 shows a breakdown of ARG missions since 1991 (see Appendix C for list of operations). The wedges of the pie chart refer to the number of operations, regardless of the number of ships involved. Therefore, a single-ship operation is counted the same as a multiple-ARG operation. Obviously, ARG ships have been called upon to carry out a wide variety of missions. Not shown on the chart are the locations of each operation, which literally span the globe.

This analysis highlights the need for flexibility within the ARG. The ships must not only be ready to conduct a full-scale wartime assault, but must also be able to adapt instantly and respond to a humanitarian crisis. Non-combatant evacuation operations (NEO) and humanitarian support missions make up over half of the operations since 1991. It would be impossible, however, to determine exactly what assets will be required for any given NEO or humanitarian support mission since they are so varied. A NEO can involve more than one ARG, as was the case during Operation Eastern Exit in Somalia in 1991, or could only require one ship, similar to Operation Noble Obelisk in West Africa in 1997. Similar examples could be made with humanitarian missions. The ability to send individual ships to different locations provides an inherent element of flexibility to efficiently conduct a variety of missions.

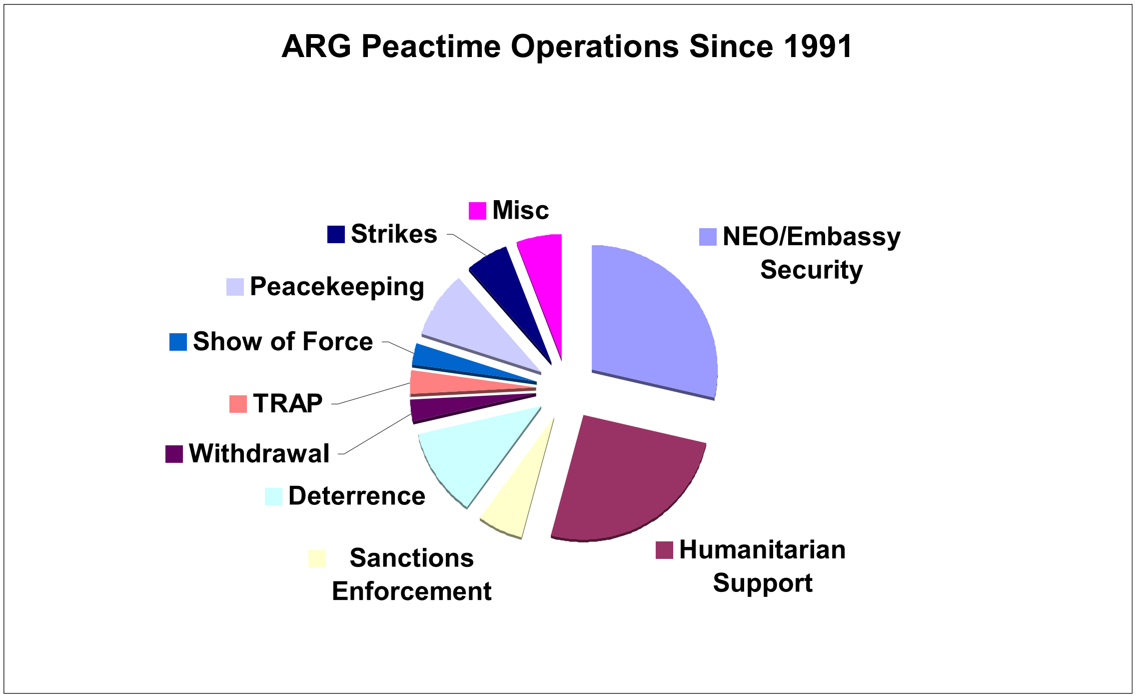

Figure 1. ARG Peacetime Operations since 1991

2.2.3 Current ARG Shortfalls

The threats discussed in Chapter 1 and the Marine Corps warfighting concepts discussed above stress the need for flexibility for facing an uncertain future. This section points out three factors that limit the flexibility of the current ARG.

Currently, the ships of the ARG are loaded such that they are dependent on each other to conduct most missions. At the beginning of a deployment, each ship is loaded with its share of the MEU equipment. The ships are loaded to maximize the amount of equipment that can be carried. For example, all the tanks may be carried on a single ship, leaving the others without any. This would leave two of the ships unable to individually carry out any operations requiring the use of tanks. Therefore, unless the operation is planned in advance, and the ship is loaded accordingly, it is very difficult for a single ship to conduct the operation independently. In fact, it would require the entire ARG pulling into port, unloading, and then reloading with a different asset distribution.

Once the ships have the assets required for their mission, another problem arises when it is time to get the equipment off the ship. The loading is carefully planned ahead of time to make the proper equipment accessible at the proper time. For example, if all the ammunition is the first thing loaded, it may not be accessible at the beginning of the operation. This severely limits the ship's ability to react as the situation changes. A sudden, unexpected change in the situation that requires a set of equipment that is buried in one of the cargo spaces would slow the reaction time of the ship and make it less adaptive and effective in carrying out its mission.

Another problem the current ARG faces is the concentration of aircraft on the LHA/LHD. Although the LSD 41 and LPD 17 have the ability to operate aircraft, they do not normally embark part of the ACE. This leaves the aircraft for the entire ACE on the LHA/LHD, making it

the only ship that could independently carry out an operation requiring a significant amount of air power.

2.2.4 Future ARG Operations

There are several ways to increase the flexibility of the ARG, making it better able to perform split-ARG operations and respond to emergent threats. The most obvious of these is to add a selective offload capability to the ARG. This would allow each ship to access any equipment onboard at any time, thus reducing its dependency of the mission plan and associated load-out.

Replacing the LHA with more than one ship is another way to add flexibility to the ARG. A two-ship LHA(R) platform could add several capabilities that are lacking in today's three-ship ARG. For the purposes of this project, there are three distinct LHA(R) combinations.

a. A modified LHD 8 complemented by a small, fast ship. In this case, the modified LHD would carry the majority of the assets and the smaller ship would be used as a high-speed ferry or could add a "lily pad" capability to the ARG, extending the range of the aircraft.

b. Two smaller LHD-type ships. These ships would have the same hull, and assets would be distributed equally between the two ships. This would allow for better distribution of assets (especially aircraft) during split-ARG operations.

c. Two completely new designs that represent a different distribution of assets. This option refers to any other combination of ships that could add flexibility to the ARG. For example, one ship could be designed to carry the assets required for a particular mission, and the other could carry all other LHA(R) requirements.

Additionally, the LHA(R) could remain a single ship, leaving the ARG with three ships. For the remainder of this report, the term LHA(R) will refer to the platform, regardless of whether it consists of one or two ships. This means that the term ARG will now mean a group of either three or four ships.

2.2.5 LHA(R) Concept of Operations (CONOPS)

Obviously, the CONOPS for this platform are dependent on the number of ships in the LHA(R) and the ARG. Even for a two-ship LHA(R), the CONOPS could vary depending on which of the three options is chosen. Every LHA(R) platform, however, must meet the same minimum requirements, no matter how many ships are involved. This fact allows the construction of a baseline notional scenario that is valid for any type of LHA(R). The baseline scenario is shown in Table 2.

Table 2 . Notional Operational Scenario

Day	Operation
0	Depart from home port
2	Arrive at embarkation port, begin embarkation of MEU(SOC)
9 – 17	Transit, cruising at 12 – 16 kts in Condition III
18 – 24	Split ARG operations: LHA(R) performs NEO
25	Join Amphibious Task Force (ATF)
26 – 39	Transit with ATF, cruising at 15 kts at Condition III
40	Arrive at Objective Area
45	Support Special Operations Forces conducting raids ashore
46	Withstand an attack by high speed surface craft
50	Conduct underway replenishment
55	Participate in full-scale opposed amphibious landing
56 – 83	Conduct fixed-wing aircraft, rotary wing aircraft and landing craft operations in support of troops ashore
72	Conduct Tactical Recovery of Aircraft and Personnel
78	Conduct UNREP, re-supply troops ashore
83	Back load Battalion Landing Team (BLT)
84 – 87	Transit to second Objective area at 20 kts, Condition III
88 – 107	Maneuver offshore under heightened air threat
95	Withstand attacks by low-flying aircraft and missiles
101	Embark reserve medical unit, provide medical support to landing force
107	Back load BLT
108 – 111	Transit to allied harbor
112	Conduct replenishment and maintenance
113 – 120	Transit to home port

2.3 Goals, Thresholds, Constraints and Standards

The MNS outlines certain key aspects of performance that the LHA(R) must achieve. It also lays out several design constraints and standards that the ship must comply with.

2.3.1 Goals and Thresholds

Since the purpose of the LHA(R) is to improve the ARG, it should be no less capable than the current LHD. For this reason, many performance factors of the LHD are used as the threshold levels for the LHA(R). Additionally, the ARG lift capacity must at least satisfy the MEU lift requirements. Other goals and thresholds will be discussed in greater detail in Chapter 3.

2.3.2 Constraints and Standards

Several constraints and standards for the LHA(R) are drawn from the MNS. The ship design must employ a total ship system architecture/engineering approach that optimizes the life cycle cost and performance. Ship design should allow for advances in technology to be readily incorporated into the ship, provide for rapid ship reconfiguration to respond to mission changes,

incorporate environmental safety and health planning throughout the life cycle to eliminate or mitigate pollution sources and health hazards, and incorporate optimized manning and maintenance concepts. Commercial standards, consistent with survivability and mission requirements, will be utilized for affordability. Navy standard equipment, existent logistic support systems, and commonality with other ship designs will be considered to minimize impact on infrastructure support requirements. The C4I systems shall be compatible with existing and planned C4I systems and equipment, comply with applicable information technology standards contained in the U.S. DOD Joint Technical Architecture (JTA), and be functionally interoperable with other U.S., NATO, Coalition, Allied and DoD component information systems. The LHA(R) must be capable of accessing standard intelligence, imagery and geospatial information databases, products and services. The ship must be able to support Naval Amphibious tactical and administrative organizations for command, control and operations, and elements of an embarked MAGTF including the Command Element (CE), Aviation Combat Element (ACE), Ground Combat Element (GCE) and Combat Service Support Element (CSSE). The ship must be designed to support both the current and future aviation and surface assault assets including helicopters, MV-22, STOVL Joint Strike Fighters (JSF), UAVs, Advanced Amphibious Assault Vehicles (AAAV), LCAC, and LCU.

2.4 Design Philosophy and Decision-Making Process

The trade-off study to determine the optimal platform for the LHA(R) requires two distinct steps, illustrated in Figure 2. First, the best distribution of assets must be determined in order to select either a single ship or one of the three two-ship options described above. Since the distribution of assets on the LHA(R) has a significant effect on the ARG capabilities, the Overall Measure of Effectiveness (OMOE) of the ARG and the cost of the LHA(R) platform are the metrics used in this study. This portion of the trade-off will be referred to as the ARG asset study.

The selection of an option for the ARG deals only with the distribution of assets, but does not determine the best hull form of the ships. A second trade-off study is required to find the best hull form for the selected option. The metrics involved in the second step of the trade-off study are platform OMOE and cost.

Both steps of the trade-off study are described in detail in Chapter 3.

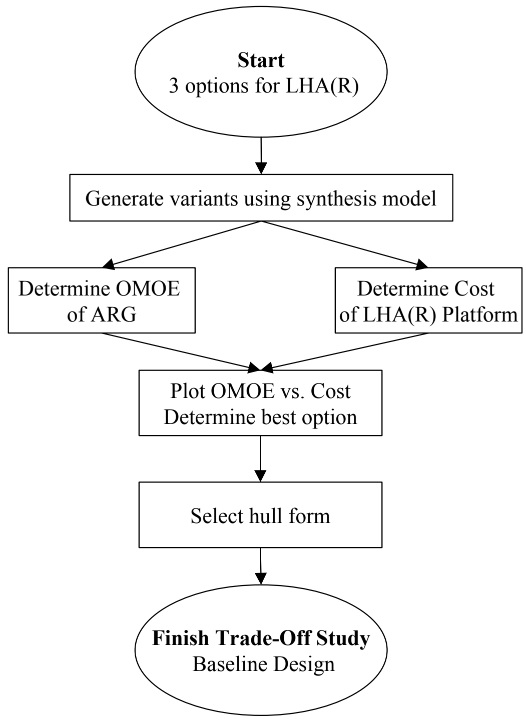

Figure 2 . Trade-off Study Process

2.5 Concept Exploration Resources

During the concept exploration phase and trade-off study, simple synthesis models are required in order to evaluate different designs.

2.5.1 MIT Math Model

Several two-ship variants are required in the first step of the trade-off study. Since the purpose of this step is only to determine the optimal distribution of assets in the ARG, all ships are assumed to be monohulls. A model that is easy to use is essential to the generation of variants in a timely manner. At the same time, the results of the trade-off study are dependent on the model, so there must be a compromise between the level of detail of the model and its ability to rapidly generate balanced ship designs. The MIT Mathcad model represents a good balance between these two attributes, but it is only valid for surface combatants and does not deal with cargo capacity, a large flight deck, or a well deck. Significant changes were required to make this model valid for large amphibious ships.

First, the model relies on curve-fits of existing surface combatant data to estimate many weights, centers of gravity, volumes and areas. Using data from ASSET models of the AD 41, AOE 6, LHD 5, LSD 41, LSD 49, T-AK 3008, T-AKR 10, T-AKR 287, T-AO 187, the curve fits were verified and/or modified to better represent a large, cargo-carrying ship.

The model was also adapted to amphibious ships by allowing the user to enter the aircraft complement, number of LCACs, cargo volume, vehicle parking area and number of troops the ship will carry. This required the addition of several calculation sections to determine the required flight deck and hangar areas, well deck area and ballast tank volume, as well as an estimation of cargo and vehicle weights. The model was validated using data from the LHD 5.

2.5.2 Advanced Hull Form Model

Six hull forms were chosen for evaluation in this study, including conventional monohulls, semi-planing monohulls, catamarans, trimarans, hydrofoils and surface effect ships. In order to complete the platform trade-off study, a synthesis model for each hull form is required. Since there are very few simple models for advanced hull forms, the design team created a rough order of magnitude (ROM) model for each of the hull forms listed.

The goal of the ROM model is to estimate the full load displacement and speed of the ship, given the payload that it carries. Three basic assumptions simplify the model, as well as provide a basis for comparing the hull forms. The baseline ship must be all-steel construction, will have 100,000 hp installed, and must meet a minimum range requirement of 5,000 nm. Using these assumptions, the payload for each variant, and data from existing ships, the ROM model estimates the full load displacement and speed of each variant. A copy of the model is included in Appendix D, along with a detailed description.

3 Concept Exploration

3.1 ARG Asset Study

The purpose of the ARG Asset study is to determine the optimal distribution of ARG assets among the ships. The ARGs examined in this study can be divided into the following groups:

a. LPD 17, LSD 41, modified LHD 8 + complement ship variants
b. LPD 17, LSD 41, two small LHD variants (2 ships with same hull)
c. LPD 17, LSD 41, two new design variants
d. LPD 17, LSD 41, single ship LHA(R) variants

The baseline ARG for this study includes an LPD 17, LSD 41, and LHD 8.

The single ship variants considered are the NAVSEA LHA(R) team designs. Table 3 lists each NAVSEA variant with a brief description and approximate displacement.

Table 3 . NAVSEA LHA(R) Variants

Variant	Full Load Displacement	Brief Description
Repeat LHD 8	42,063 ltons	LHD 8 with new island
Plug	48,775 ltons	Expanded LHD 8 hull
Plug +	48,920 ltons	Plug with enhanced survivability features
New Plug Equivalent	62,016 ltons	Same capability as Plug +
Large ACE	64,088 ltons	Capabilities of new plug equivalent with 37 a/c ACE
Dual Tramline	69,006 ltons	37 a/c ACE with full concurrent flight ops
Small LHD	31,995 ltons	¾-scale LHD

3.1.1 ARG Variant Definition

In order to define the design space, each two-ship option consists of a large ship and small ship. The amphibious lift capacity of the small ship is the dominant factor in determining which of the three options the two-ship combination will fall under. For example, a small ship that carries no LCACs and only a few aircraft could only complement a ship with an amphibious lift capacity similar to that of an LHD, whereas a small LHD carrying 2 LCACs and approximately half of the ACE would be an ideal ship for the two small LHD option.

Based on these observations, the design space is defined by the amphibious lift capacity of the small ship. In order to reduce the required number of variants, the factors are limited to the number of LCACs, number of aircraft and cargo volume onboard. These three factors were chosen due to their relative importance as well as their impact on the size of the ship. The number of LCACs is varied from 0 to 2, number of aircraft is varied from 0 to 14, and cargo volume is varied from 10,000 ft^3 to 95,000 ft^3.

In order to fully explore the design space, ships would have to be balanced using every possible combination of factors. This is obviously not feasible, as it would involve many ship designs and hundreds of man-hours. Using Design of Experiments, however, the number of

required variants can be reduced to a more manageable number. The statistical analysis software package JMP, created by the SAS Institute, is used to generate a design of experiments using the Box-Behnken method. For the three factors defined above, the design space can be covered reasonably well using only 15 variants, summarized in Table 4. It should be noted that the Box-Behnken method does not include the extreme point designs (i.e., the highest value for all three factors).

Table 4. Small Ship Variants

Variant	# LCACs	# Aircraft	Cargo Volume (ft^3)
1	1	14	10,000
2	0	0	52,500
3	1	0	10,000
4	1	7	52,500
5	2	7	10,000
6	0	7	95,000
7	0	14	52,500
8	0	7	10,000
9	2	0	52,500
10	1	14	95,000
11	2	14	52,500
12	2	7	95,000
13	1	7	52,500
14	1	0	95,000
15	1	7	52,500

Each small-ship variant is balanced using the MIT Amphibious Ship Mathcad Model discussed in Section 2.6.1. For each ship, the number of LCACs and aircraft, and the cargo volume are fixed, leaving other ship characteristics such as length, beam, speed and range, as well as the other amphibious lift components of troops and vehicle parking area to be adjusted to balance the ship.

Once the small ship for each variant is balanced, the large ship must be defined and then balanced. The same factors are used for the large ship, and the value for each variant is determined by subtracting the small ship value from an LHA(R) total value. The LHA(R) totals are assumed to be 3 LCACs (the capacity of the LHD 8), 31 aircraft (the estimated size of the future ACE), and 190,000 ft^3 of cargo space (twice the amount a ¾-scale LHD can carry). For some of these variants, values for each factor are similar to the small ship it complements. In these cases, the same hull is used, and some of the area inside is reallocated to meet the differing requirements. In other cases, the large ship values are very similar to those of an LHD 8 (3 LCACs, 31 aircraft, 125,000 ft^3 cargo space). In these cases the LHD 8 hull form is used, with space allocation differences to account for the slightly different requirements. For all other cases, a completely new ship is balanced. Table 5 summarizes the factors for each large-ship variant. A summary of the balanced designs appears in Appendix E.

Table 5. Large Ship Variants

Variant	# LCACs	# Aircraft	Cargo Volume (ft^3)	Option
1	2	17	180,000	New designs
2	3	31	137,500	Mod LHD 8
3	2	31	180,000	Mod LHD 8
4	2	24	137,500	New designs
5	1	24	180,000	Same hull
6	3	24	95,000	Mod LHD 8
7	3	17	137,500	New designs
8	3	24	180,000	Mod LHD 8
9	1	31	137,500	New designs
10	2	17	95,000	New designs
11	1	17	137,500	Same hull
12	1	24	95,000	New Designs
13	2	24	137,500	New designs
14	2	31	95,000	Mod LHD 8
15	2	24	137,500	New designs

3.1.2 ARG OMOE Model

The ARG OMOE Model is a weighted sum model that quantifies the effectiveness of the ARG. The overall effectiveness is broken down into different capabilities, including mobility, survivability, amphibious lift capacity and mission flexibility. Each capability is further broken down into measures of performance (MOPs). Table 6 lists the capabilities, MOPs, and the goal and threshold values for each MOP. Since one of the purposes of this OMOE model is to compare three-ship and four-ship ARGs, it is important that it is not biased towards any specific number of ships.

The weightings of the capabilities and Measures of Performance are the key to the model. If they do not reflect the customer (warfighter) desires and preferences, the model will be useless in determining the effectiveness of the ARG. A survey of several Navy and Marine Corps officers (current and former) provided comparisons of different capabilities and MOPs, allowing the development of the weightings shown in Table 7. The survey and a more detailed analysis of the data appear in Appendix F.

Table 6. Capabilities, MOPs, Goals and Thresholds for ARG OMOE Model

Capability	MOP	Goal	Threshold
Mobility	Sustained Speed	30 kts	20 kts
	Range	10,000 nm	5,000 nm
Survivability	Area Defense	1	0
	Distribution of Assets	25 %	75 %
Amphibious Lift Capacity	Aircraft	40	31
	LCAC	8	2
	Cargo Volume	400,000 ft^3	200,000 ft^3
	Vehicle Parking Area	45,000 ft^2	15,000 ft^2
	Troops	5,000	2,500
Mission Flexibility	Selective Offload Capability	100 %	0 %
	Mission-Mobility Factor	1.5	1

Table 7. ARG OMOE Model Capability and MOP Weightings

Capability Weighting	Capability	MOP Weighting	MOP
0.141	Mobility	0.085	Sustained Speed
		0.056	Range
0.211	Survivability	0.135	Area Defense
		0.076	Distribution of Assets
0.282	Amphibious Lift Capacity	0.097	Aircraft
		0.044	LCAC
		0.046	Cargo Volume
		0.031	Vehicle Parking Area
		0.063	Troops
0.366	Mission Flexibility	0.201	Selective Offload Capability
		0.165	Mission-Mobility Factor

3.1.2.1 Mobility

The mobility of the ARG is broken down into two MOPs: sustained speed and range. Since the ARG's mobility depends only on its most limited ship, that is the only speed or range used in this section of the OMOE model. For example, the ARG cannot steam as a group any faster than the sustained speed of the slowest ship, so the slowest ship speed is the only one used in the mobility section of the OMOE model. Since only one ship speed and range are used, the number of ships in the ARG does not have any effect on these MOPs.

3.1.2.2 Survivability

Survivability is also divided into two MOPs: area defense capability and the distribution of assets. Area defense measures the ability of the ARG to defend itself against all types of enemy threats, including air, surface, and subsurface. Since it is a measure for the entire ARG, all the area defense capabilities could be concentrated on a single ship, as long as they have the

range to protect the whole ARG (while operating as a group). In this study, the area defense capabilitly is held constant at 1. The distribution of assets deals with how much of the total ARG assets would be lost with the loss of a single ship. A three-ship ARG with 70% of its assets on a single ship would lose more with the loss of that ship, and therefore would be less survivable than a four-ship ARG with 25% of its assets on each ship. On this MOP, ARGs with more ships have the potential for a higher score, but it is not a predetermined result. An equally distributed three-ship ARG would score higher than a four-ship ARG with greater than 34% of its assets on a single ship. The percentage of assets is calculated using the following formula:

$$\begin{aligned}\%Assets_{ARG} &= 0.157\cdot\left(\frac{LCAC_{ship}}{LCAC_{ARG}}\right)+0.345\cdot\left(\frac{A/C_{ship}}{A/C_{ARG}}\right)+0.164\cdot\left(\frac{Cargo_{ship}}{Cargo_{ARG}}\right)\\ &+0.111\cdot\left(\frac{Vehicle_{ship}}{Vehicle_{ARG}}\right)+0.222\cdot\left(\frac{Troops_{ship}}{Troops_{ARG}}\right)\end{aligned} \tag{1}$$

The coefficients for this equation are drawn from the survey and represent the relative importance of the elements of amphibious lift.

3.1.2.3 Amphibious Lift Capacity

The MOPs for amphibious lift capacity are the total number of aircraft, number of LCACs, cargo volume, vehicle parking area and number of troops carried by the ARG, making this section of the OMOE model very straightforward, and not at all dependent on the number of ships.

3.1.2.4 Mission Flexibility

For the purposes of this project, Mission Flexibility is defined as the ability of the ARG to perform split-ARG operations and respond to emergent situations. The ability to perform split-ARG operations increases the sphere of influence of the ARG by sending individual ships to different geographic locations to accomplish missions simultaneously. The ability to respond to emergent situations could refer to the whole ARG, or a split-ARG. Both of these capabilities have the same set of enablers.

First, selective offload is very important. For split-ARG operations, each ship must have mission-appropriate equipment onboard. Also, as the situation changes, the ship must be able to access all the equipment onboard, even if its use is unexpected.

The mission capability of each ship is also an enabler for both capabilities. If the ships are to operate independently, they each must have some mission capability. Similarly, in response to an emergent situation, if the ARG includes a fast ship that can arrive in theater quickly, it must be able to perform some missions to be effective. Finally, the speed and range of the individual ships enables a rapid response while operating independently or with the group.

The most obvious MOP for Mission Flexibility is Selective Offload Capability. The selective offload MOP is simply the percentage of the cargo capacity of the ARG that has selective offload capability, so it does not depend on the number of ships or the total cargo volume of the ARG.

Speed and mission capability of each ship are also important to mission flexibility. The speed of the fastest ship in the ARG does not give an accurate picture, because it does not take into account the mission capabilities of the ship once it arrives in theater. Getting there fast is

good, but only if it is able to do something once there. Therefore, the Mission-Mobility Factor (MMF) is used to combine the mission capability and mobility of each ARG ship.

Mission capability of a ship is very difficult to determine because mission definitions are not standard and even similar missions vary greatly in scale. Instead of trying to determine some direct measure of mission capability, an indirect method can be used by measuring the mission enablers, which are the aircraft, LCACs, cargo, vehicles, and troops that are onboard each ship. The mission factor for each ship is calculated using equation 2. Again, the coefficients are drawn from the survey. Also, the normalization of each amphibious lift element allows the MMF to only deal with the distribution of amphibious lift assets, not the amount it can carry.

$$Mission_{ship} = 0.157 \cdot \left(\frac{LCAC_{ship}}{LCAC_{ARG}} \right) + 0.345 \cdot \left(\frac{A/C_{ship}}{A/C_{ARG}} \right) + 0.164 \cdot \left(\frac{Cargo_{ship}}{Cargo_{ARG}} \right) + 0.111 \cdot \left(\frac{Vehicle_{ship}}{Vehicle_{ARG}} \right) + 0.222 \cdot \left(\frac{Troops_{ship}}{Troops_{ARG}} \right) \quad (2)$$

The mobility factor for each ship is calculated using equation 3. It is simply a normalized speed of the ship.

$$Mobility_{ship} = \frac{V_{ship}}{21kts} \quad (3)$$

Once the Mission and Mobility factors for each ship have been calculated, the ship's MMF can be calculated by multiplying the mission and mobility factors, as shown in equation 4. Finally, equation 5 shows the calculation of the MMF of the ARG.

$$MMF_{ship} = Mission_{ship} \cdot Mobility_{ship} \quad (4)$$

$$MMF_{ARG} = \sum_{\#ships} MMF_{ship} \quad (5)$$

It should be noted that the MMF of the ARG is not dependent on the number of ships in the ARG or the amphibious lift capacity of the ARG. The only way to increase the MMF is to move a greater percentage of assets at a higher speed.

3.1.3 Cost Model

The lifecycle cost of each variant is determined using the MIT Mathcad Cost Model. This model is weight-based and gives a good estimate of the cost of each ship. The lifecycle cost is determined for the entire class of both LHA(R) ships, assuming there are 4 ships in each class and the ships have a 30 year service life.

Two of the cases studied require special treatment using this model. First, the variants involving the modified LHD 8 do not have a lead ship cost associated with the LHD 8. The complement ship class does have a lead ship and three follow-on ships, but the modified LHD 8 class consists of four follow-on ships. The variants with two ships of the same hull form are treated as a single class with one lead ship and 7 follow-on ships.

3.1.4 OMOE vs. Cost Plot

Once the cost and OMOE have been determined for each variant, they are plotted as shown in Figure 3. The four types of ARG fall into four distinct groups on this plot. All the variants have a significant increase in OMOE over the baseline (LPD 17, LSD 41 and LHD 8), but they also cost more. The dashed line on the plot represents the Pareto frontier, which shows the greatest OMOE that can be achieved for any given cost. While it would take an infinite number of variants to accurately determine the Pareto frontier, it can be estimated from the variants already plotted. The points along the Pareto frontier are called non-dominated variants, and should be the only ones seriously considered for selection. The variants below the Pareto frontier are called dominated variants because another variant exists that achieves a higher OMOE for the same cost.

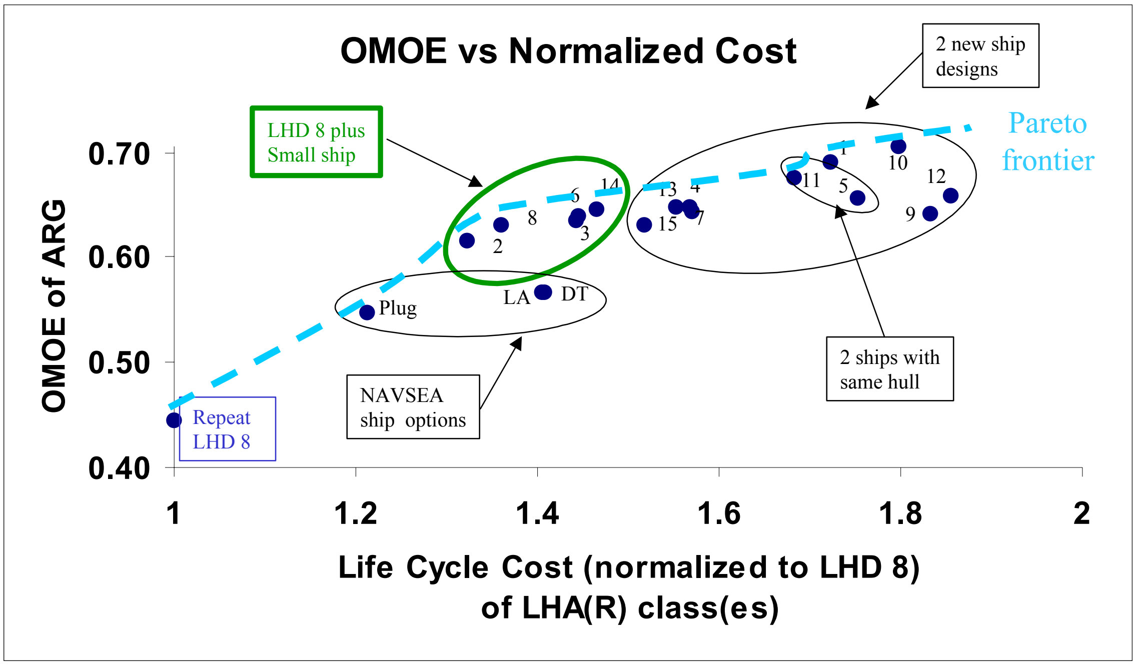

Figure 3 . ARG OMOE vs. Cost

The ideal variant would appear in the upper left corner of this plot, having the same cost as the LHD 8 and an OMOE of 1. While there are no variants at this point, some are closer than others. The three-ship ARG containing the Plug design represents a significant improvement in OMOE from the LHD 8, without too much increase in cost. The LHD 8 plus complement ship ARG dominates the other three-ship ARGs. The two new designs and two small LHD options can produce greater OMOEs, but have significantly increased costs compared to the LHD 8.

3.1.5 ARG Variant Selection

Based on the plot in Figure 3, the ARG containing the LHD 8 and a complement ship is selected. Of the five variants in this group, 2 and 8 have the lowest cost and form a small subset of the group. The focus is on these two variants in determining the payload for the complement ship. Table 8 summarizes the payload of these two variants.

Table 8 . Payload Summary of Variants 2 and 8 Complement Ships

	Variant 2	Variant 8
# Aircraft	0	7
# LCAC	0	0
Cargo Volume	52,500	10,000
Vehicle Parking Area	0	0
Troops	165	225

Based on the payload of these two variants, the following ranges of amphibious lift capacity will be considered for the complement ship:

LCACs:	0
Aircraft:	0 – 7 (no JSF)
Cargo Volume:	10,000 – 52,500 ft^3
Vehicle Parking:	0 – 1,000 ft^2
Troops:	100 – 200 people

The next step in the trade-off process is to determine the exact payload and hull form for the complement ship.

3.2 Platform Trade-off Study

The selected LHA(R) option of a modified LHD 8 plus a small complement ship requires a conversion or modification of the LHD 8 as well as a new design for a complement ship. The LHD 8 modification will be briefly addressed later in the report, but the focus of the rest of this study is on the small complement ship.

The platform trade-off study is designed to answer two major questions about the complement ship. First, what should the payload be, and second, what hull form will make the ship most effective?

3.2.1 Complement Ship Variants

Payload is again used to define the variants. It has already been determined that the complement ship will not carry any LCACs, leaving only aircraft, cargo volume, vehicle parking area, and troops as the factors in this experiment. Each is varied according to the ranges listed in section 3.1.5. A Central Composite Design of Experiments is used to minimize the number of variants and still adequately cover the design space. The Central Composite Method includes the extreme point designs so the response surface will be more accurate in these regions. Using the JMP software, 25 variants are created, listed in Table 9. Each of these variants will have to be balanced using every hull form to be examined.

Table 9. Platform Trade-off Study Variants

Variant	Aircraft	Cargo Volume (ft^3)	Vehicle Parking Area (ft^2)	Troops
1	1	52,500	1000	100
2	1	10,000	0	200
3	7	10,000	0	200
4	7	10,000	1000	200
5	1	10,000	1000	200
6	7	52,500	0	100
7	7	52,500	0	200
8	1	52,500	1000	200
9	1	52,500	0	200
10	4	31,250	0	150
11	4	31,250	500	200
12	4	31,250	500	100
13	1	52,500	0	100
14	7	10,000	1000	100
15	1	31,250	500	150
16	7	31,250	500	150
17	1	10,000	0	100
18	4	31250	500	150
19	4	10,000	500	150
20	1	10,000	1000	100
21	7	52,500	1000	200
22	4	52,500	500	150
23	4	31,250	1000	150
24	7	52,500	1000	100
25	7	10,000	0	100

Each variant is balanced using the advanced hull form model outlined in Section 2.6.1. The payload and hull form are entered for each variant, and then the appropriate fuel weight must be determined to achieve the desired range of 5000 nm. In many cases, the amount of fuel required to meet this requirement made the ship so large that it could no longer achieve a sustained speed of at least 22 kts. These variants were ruled out immediately, and included all of the catamaran, SES and hydrofoil variants as well as some of the SWATH variants. A full summary of each variant is included in Appendix G.

3.2.2 Platform OMOE Model

The platform OMOE model is very similar to the ARG OMOE model, except that it only applies to the complement ship. The capabilities are identical, with only the MOPs, goals and thresholds changing. The following sections outline the differences in the ARG OMOE and Platform OMOE Models. Table 10 lists the capabilities, MOPs, and goal and threshold values

for the platform OMOE model. Weightings for the capabilities and MOPs are derived from the survey results in Appendix F, and are listed in Table 11 .

Table 10. Capabilities, MOPs, Goals and Thresholds for Platform OMOE Model

Capability	MOP	Goal	Threshold
Mobility	Sustained Speed	40 kts	20 kts
	Range	10,000 nm	2,500 nm
	Seakeeping	SS 6	SS 4
	Stores Period	45 days	20 days
Survivability	Self Defense	1	0
	Distribution of Assets	50 %	1 %
Amphibious Lift Capacity	Aircraft	7	0
	LCAC	4	0
	Cargo Volume	52,500 ft^3	10,000 ft^3
	Vehicle Parking Area	1,000 ft^2	0 ft^2
	Troops	200	100
Mission Flexibility	Selective Offload Capability	100 %	0 %
	Mission-Mobility Factor	1.5	1

Table 11. Platform OMOE Model Capability and MOP Weightings

Capability Weighting	Capability	MOP Weighting	MOP
0.136	Mobility	0.037	Sustained Speed
		0.025	Range
		0.045	Seakeeping
		0.029	Stores Period
0.205	Survivability	0.131	Self Defense
		0.073	Distribution of Assets
0.273	Amphibious Lift Capacity	0.094	Aircraft
		0.043	LCAC
		0.045	Cargo Volume
		0.030	Vehicle Parking Area
		0.061	Troops
0.386	Mission Flexibility	0.178	Selective Offload
		0.208	Mission-Mobility Factor

3.2.2.1 Mobility

In the case of the platform model, all aspects of mobility refer to the complement ship. The advanced hull form model provides a speed and range for each variant, but does not do any calculations regarding seakeeping. In order to complete the study, seakeeping is held at a constant value (SS 6) for each variant. Stores period refers to the amount of provisions and general stores the ship carries, and is an input into the advanced hull model. For the purposes of this study, it is held constant at 30 days.

3.2.2.2 Survivability

Survivability is broken into the same two MOPs as in the ARG model, but this time the self-defense capability refers only to the two-ship LHA(R) platform. For this study, the self-defense capability is held constant at 0.3. Additionally, the distribution of assets is a measure of the percent of LHA(R) assets carried by the complement ship.

3.2.2.3 Amphibious Lift Capacity

The only change in the amphibious lift capacity is in the goal and threshold values. Instead of being targeted toward the entire ARG, they only measure the lift capacity of the complement ship.

3.2.2.4 Mission Flexibility

Since selective offload capability is important to have on the LHA(R), the measure of selective offload does not change for the platform model. The mission-mobility factor is not as useful in the platform study, however, since all the variants have a similar breakdown. For the purposes of this study, the mission-mobility factor is held constant at 1.5, and does not affect the relative OMOEs of each variant.

3.2.3 Platform Cost Model

At this early stage in the design process, it is difficult to estimate the cost of ships of different hull forms. Most cost models are weight-based, however, making the displacement of the ship a major factor in the cost calculations. Instead of comparing costs, displacements of the variants are compared during the trade-off study. Each hull form is expected to have a different cost per ton, making comparisons between hull forms very difficult. For the purposes of this study, the cost per ton of a monohull is considered to be less than that of any other hull form, but is not quantified due to a lack of data.

3.2.4 Hull Form Selection

According to the advanced hull form model, only the trimaran, monohull and semi-planing monohull can meet both the speed and range requirements simultaneously. Using the 25 balanced variants for each hull type and the JMP® software, response surface equations can be developed for the OMOE and displacement of each ship. Using these equations, the cost and OMOE for hundreds of other variants can be estimated. Figure 4 shows a plot of OMOE vs. displacement for the three different hull forms. In this plot, the optimal point is again in the upper left-hand corner, where a ship would have a very high OMOE and a small displacement. The Pareto boundaries for each hull form are clearly visible in this plot. The trimaran variants are the non-dominated solutions. The monohull variants are slightly heavier and have slightly lower OMOEs (due to the superior speed of the trimarans), but have far less associated risk. The semi-planing monohull variants are dominated solutions and are ruled out.

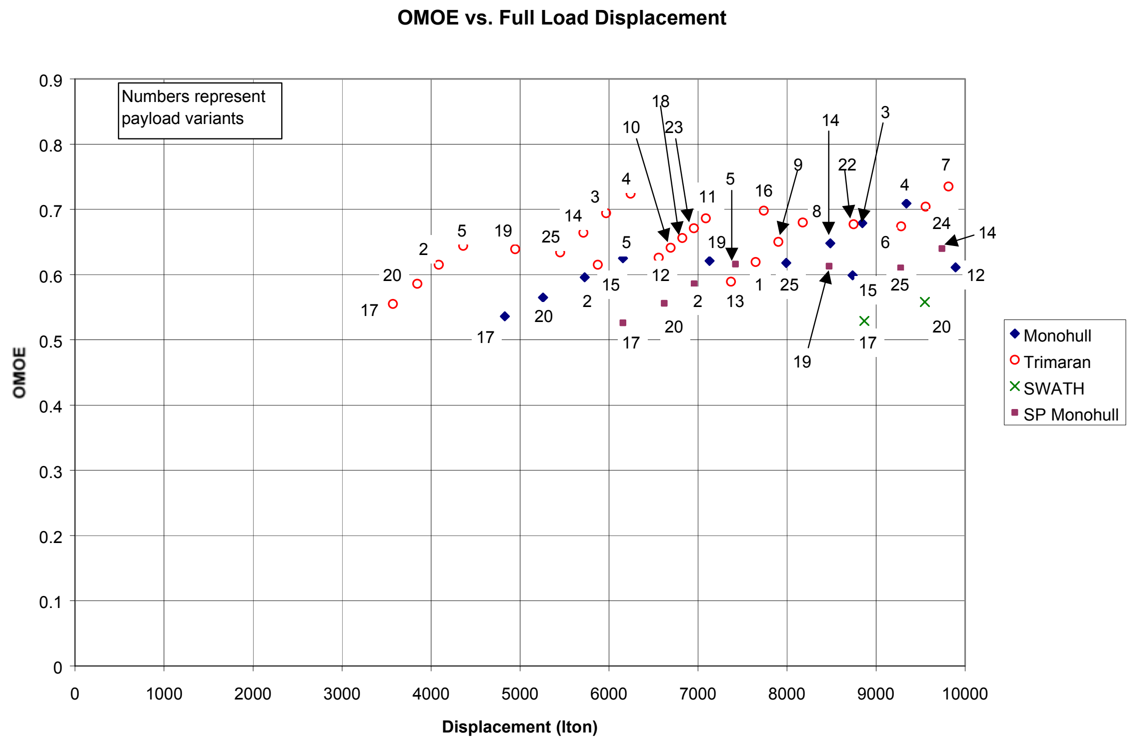

Figure 4. Platform OMOE vs. Displacement

The trimaran design has many advantages over a monohull. The most obvious is an approximately 20% decrease in resistance at high speeds, allowing the ship to either achieve higher speeds or operate with a smaller propulsion plant. Additionally, the separation of the side hulls from the main hull allows increased protection of vital equipment in the main hull while increasing the GM of the ship giving it more transverse stability. This leads to more flexibility in arranging heavy equipment and provides much larger growth margins than a conventional monohull. Perhaps the most attractive feature of the trimaran for a small amphibious ship is the large amount of deck area near amidships. Locating the flight deck very close to the center of pitch can reduce the flight deck motions. Finally, the trimaran's relatively shallow draft makes it well suited for littoral operations.

The trimaran does have a significant amount of risk associated with it. Currently, the largest trimaran in existence is the RV Triton, at only 1100 ltons. Also, there are a lot of questions concerning the structural design and seakeeping performance of a trimaran. The structure is much more complex than that of a monohull, particularly at the joints between the cross-deck and hull structures. While preliminary tests show that trimarans area able to maintain their speed in head seas better than monohulls, most of these are model tests that have not been validated at full-scale. Additional seakeeping questions arise concerning the roll period and slamming of the cross-deck structure.

Undoubtedly, the research and development of new construction procedures will make a trimaran more expensive than a monohull. Based on the monohull variants, a monohull complement ship displacing between 9,000 and 10,000 ltons could meet the requirements and

achieve a reasonable OMOE. In order to keep the trimaran cost competitive with that of a monohull, the trimaran displacement is limited to 7000 ltons for the baseline design.

3.2.5 Baseline Payload Determination

The variants within each hull type form several distinct diagonal lines on the plot in Figure 4. Each diagonal line represents a different combination of aircraft and cargo volume. Figure 5 shows several groupings for the 25 original trimaran variants. As expected, the variants with 1 aircraft and 10,000 ft^3 cargo volume are the smallest, but also have relatively low OMOEs. The variants with 7 aircraft and 10,000 ft^3 cargo volume are larger, but have significantly increased OMOE values. These effects can be seen more clearly using Response Surface Methods to analyze the design space.

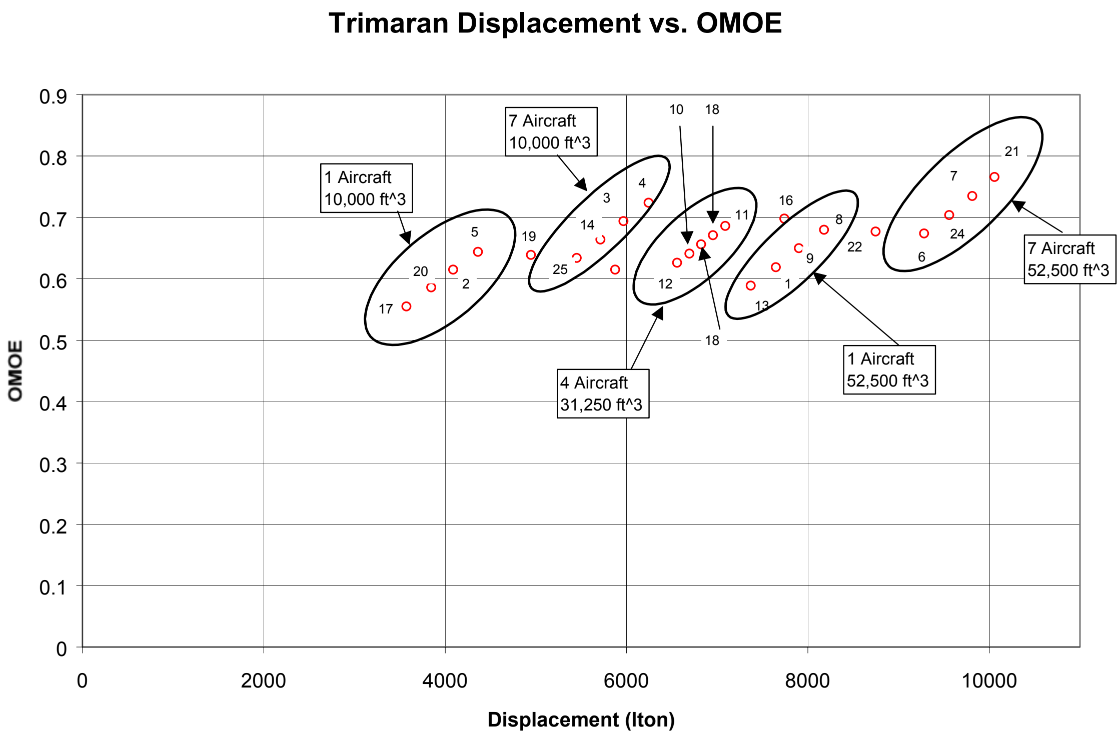

Figure 5. Trimaran Variants OMOE vs. Displacement

Using the Fit Model tool in JMP to create response surfaces for the trimaran allows the investigation of designs other than the 25 point designs. First, the prediction profiler, shown in Figure 6, can provide an insight into the effect of each payload element on the ship size and OMOE. The figure is very straightforward. A flat curve means that the factor (payload element) has very little effect on the response (OMOE or displacement), while a steep slope indicates a large effect. The prediction profiler shows that the number of aircraft has the most significant effect on OMOE, with the maximum number of aircraft leading to the highest OMOE. Adding aircraft to the ship does significantly increase the size, but does not make the ship unacceptably large. On the other hand, the cargo volume has a tremendous effect on the size of the ship. When the cargo volume is maximized, the ship size also reaches a maximum. This is also seen

in Figure 5, where the variants with 52,500 ft^3 cargo volume have displacements of approximately 10,000 ltons.

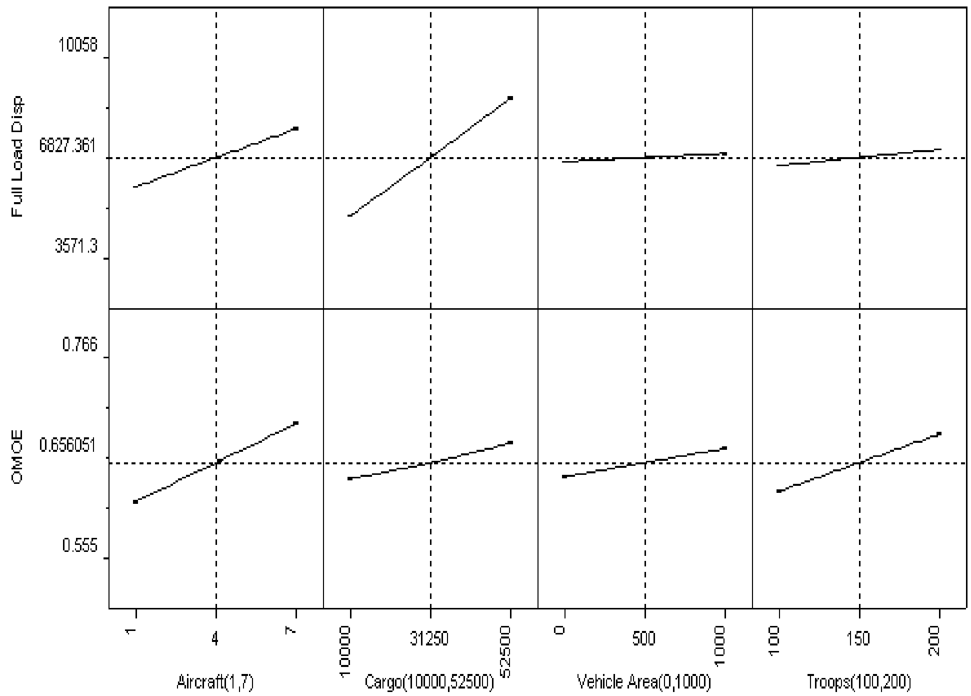

Figure 6. Prediction Profiler for Trimaran

A few decisions can be made based on observations from the prediction profiler. First, the troops and vehicle parking areas do impact the OMOE of the ship, but have almost no effect on the size. Both of these can be maximized with very little penalty. Next, maximizing the number of aircraft will drastically increase the OMOE, but may cause the displacement to exceed the 7000 lton limit. The final determination will be the amount of cargo the ship can carry. Both of these questions can be investigated using the contour profiler in JMP. The contour profiler uses curve fits calculated from the 25 point designs to estimate the characteristics of ships with any combination of payload elements. Figure 7 shows the design space contours in the aircraft-cargo plane, with the troops and vehicle parking area set to their maximum values. The shaded area represents the area in which the ship will exceed the 7000 lton limit. Moving within the feasible design space (the white region), the OMOE and ship displacement is instantly calculated by JMP. The highest OMOE in the feasible space occurs at 7 aircraft and about 17,000 ft^3 cargo volume. This point represents the baseline design.

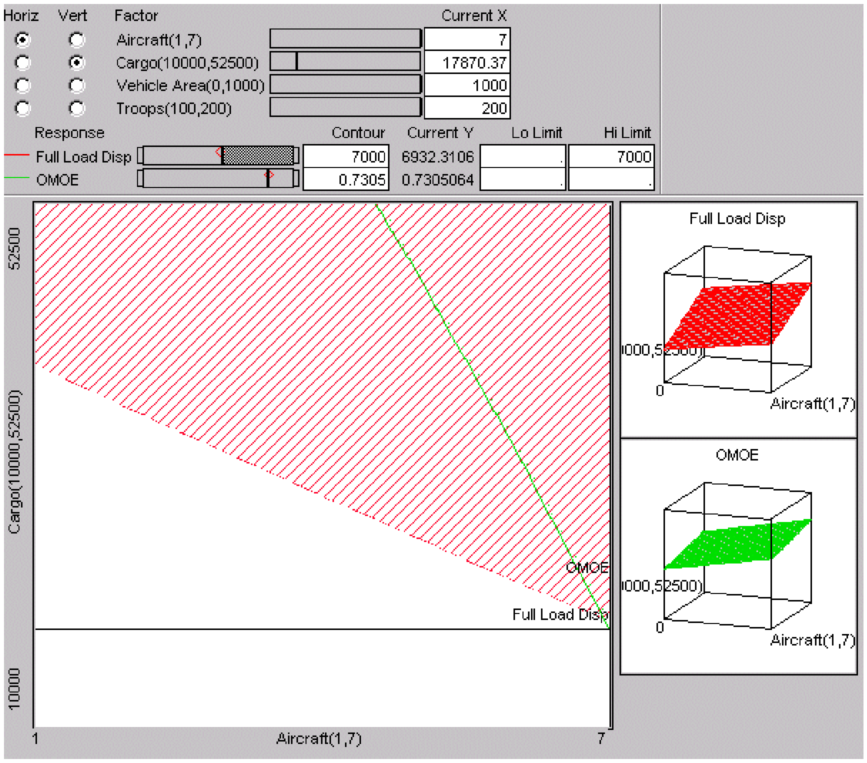

Figure 7. Contour Profiler for Trimaran

3.3 Baseline Design

The baseline design for the LHA(R) is a 7000 lton trimaran with the amphibious lift capacity shown in Table 12.

Table 12 . Baseline Trimaran Characteristics

Displacement	7000 lton
Sustained Speed	33 – 35 kts
Range	5000 nm
Aircraft	7
Cargo Volume	15,000 ft^3
Vehicle Parking Area	1,000 ft^2
Troops	200

4 Feasibility Study and Assessment

4.1 Design Tool Integration

Designing a trimaran presented several challenges due to the lack of a single, integrated design tool such as ASSET. The feasibility study requires the integration of several different design tools.

4.1.1 Overview

After a survey of the available design tools, the team selected primary and secondary tools for each major aspect of the ship. Table 13 list the tools used in this study.

Table 13: Trimaran Design Tools

	Primary Design Tool	**Secondary Design Tools**
Hydrostatics	SHCP	ASSET
Resistance	TriSET	ASSET
Area/Volume	ASSET	Excel, POSSE
Structures	MAESTRO	
Weights	ASSET	Excel, MAESTRO
Seakeeping	MathCad	

4.1.2 Hydrostatics

A trimaran design tool called TriSET was used initially to create the hull offsets and do the preliminary hydrostatic calculations. TriSET is a Visual Basic program developed by a group of MIT students in 1999. It runs in an Excel spreadsheet, and manipulates ASSET so that a trimaran can be modeled.

An important concept in modeling a trimaran in ASSET is the equivalent monohull. Figure 8 shows a set of offsets for a trimaran. As expected, there is a large gap between the main hull and the side hulls. In Figure 9, however, the side hulls have been shifted inboard so that they effectively form a monohull.

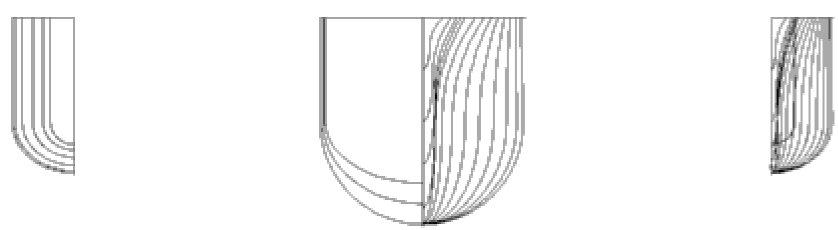

Figure 8: Trimaran Offsets

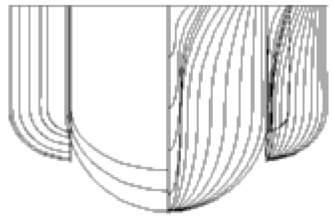

Figure 9: Equivalent Monohull Offsets

There are three major side hull designs that can be used in a trimaran. These include symmetric, asymmetric inboard, and asymmetric outboard and are shown in Figure 10 [7]. Asymmetric outboard side hulls are used in the design to facilitate the use of the equivalent monohull. This equivalent monohull has the same submerged volume as the trimaran, making draft calculations accurate. Additionally, the longitudinal stability characteristics are similar to the trimaran. Obviously, with no space between the side hulls and main hull, the transverse stability characteristics are not the same and must be dealt with separately.

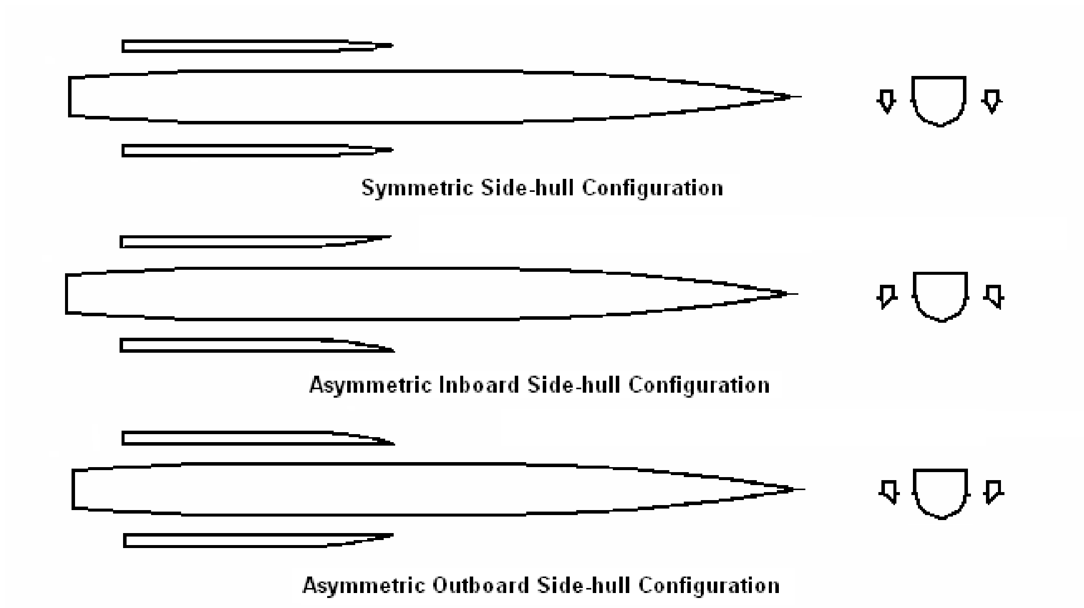

Figure 10: Trimaran Side Hull Configurations [7]

A NAVSEA design tool called Ship Hull Characteristics Program (SHCP) Version 4.3x provides a more detailed analysis of the trimaran. It evaluates the basic hydrostatic characteristics of the ship as well as the floodable length and intact and damaged stability characteristics. SHCP provides more accurate data than ASSET because it is able to handle a

trimaran model, not just an equivalent monohull. Appendix H contains the input files used by SHCP.

4.1.3 Resistance

While the resistance of a monohull can be modeled using a variety of methods, it is much more difficult to determine the resistance of a trimaran. As discussed in Section 4.1, a combination of programs is required to calculate the trimaran's resistance. Since the model in ASSET does not have any separation between the main hull and side hulls, the resistance calculations for this hull form will not be accurate.

A trimaran's total resistance depends on the bare hull resistance (R_{BH}), wind resistance (R_W), and appendage resistance (R_{APP}). The bare hull resistance includes the residual resistance of the main hull (R_{Rmain}), the frictional resistance of the main hull (R_{Fmain}), the residual resistance of the side hulls (R_{Rside}) and the frictional resistance of the side hulls (R_{Fside}), as well as an interference factor to account for increased (or decreased) resistance due to wave interactions between the hulls. The flowchart in Figure 11 illustrates the resistance calculation for a trimaran.

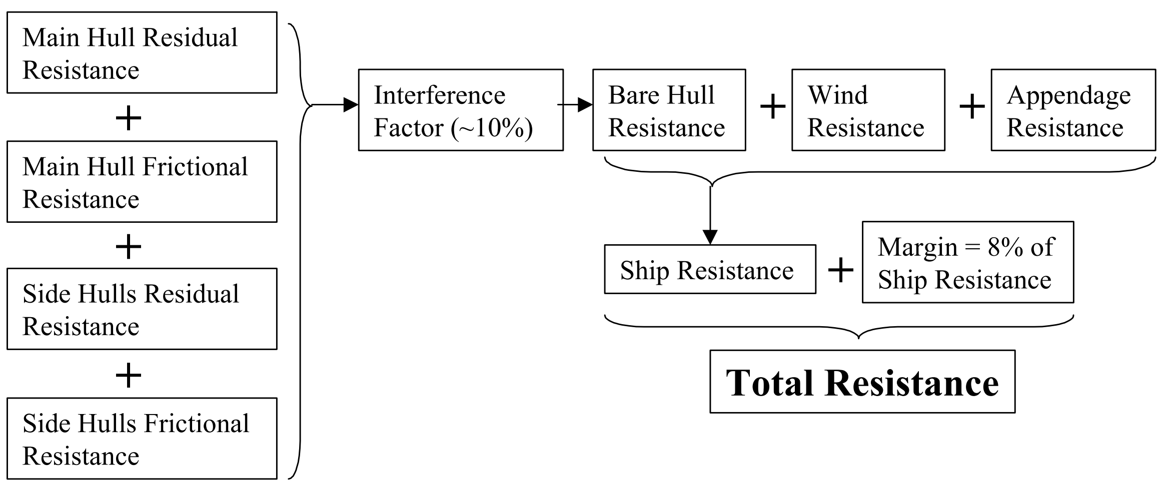

Figure 11: Resistance Calculation Process

TRISET manipulates ASSET to calculate the residual resistance of both the main hull and side hulls. Empirical data suggests that the interference factor could be anywhere from –10% to +40% [8]. Based on the results in reference 7, the interference factor is assumed to be 10%. Equation 6 shows the calculation of the trimaran's bare hull resistance.

$$R_{BH} = 1.1 \cdot (R_{Rmain} + R_{Fmain} + R_{Rside} + R_{Fside}) \qquad (6)$$

The wind resistance depends on the frontal area of the ship, and is calculated using equation 7.

$$R_W = \frac{1}{2} C_A \cdot \rho_A \cdot A_F \cdot V^3 \qquad (7)$$

where: C_A = air resistance coefficient (0.7)

ρ_A = density of air

A_F = frontal area of ship
V = ship speed (in ft/s)

The appendage resistance depends on the type, shape and size of the appendages. A ship with open struts and shafts will have very different appendage resistance characteristics than a ship with podded propulsion. The LHA(R) complement ship has podded propulsors for a variety of reasons that will be discussed in Section 4.2.3. No other appendages are considered in these calculations. To determine the resistance of a pod as a function of speed, a conventional monohull ASSET model served as a test platform. By varying the number of pods on the hull and running a total resistance calculation, a "per pod" resistance can be determined. Equation 8 calculates the resistance of a pod. In this case, the ship speed is in knots. Equation 9 calculates the total appendage resistance.

$$R_{pod} = 1.2276 \cdot V^{2.3} \tag{8}$$

$$R_{APP} = N_{pods} \cdot R_{pod} \tag{9}$$

Equation 10 shows the effective horsepower (EHP) to move the ship through the water. It includes each component of resistance calculated above, as well as an 10% design margin

$$EHP = 1.1 \cdot (R_{BH} + R_W + R_{APP}) \tag{10}$$

The shaft horsepower (SHP) is related to the EHP by the propulsive coefficient (PC). Equation 11 shows the relationship between SHP and EHP. A typical monohull with rudders and open struts and shafting has a PC of approximately 0.67. Replacing the traditional rudder, struts and shaft with azimuthing pods serves to increase the PC, as many of the losses are reduced. A conservative estimate is a 5% increase in PC, bringing it to a value of 0.72.

$$SHP = \frac{EHP}{PC} \tag{11}$$

The installed power (P_{IREQ}) must be greater than the SHP to ensure that the ship can achieve its sustained speed in less than ideal conditions. A 25% margin is an accepted value to account for sea state and fouling. Equation 12 shows the final installed power calculation.

$$P_{IREQ} = 1.25 \cdot SHP \tag{12}$$

The curves in Figure 12 are generated using the method outlined above. These curves can be used to determine the power required to achieve a given speed.

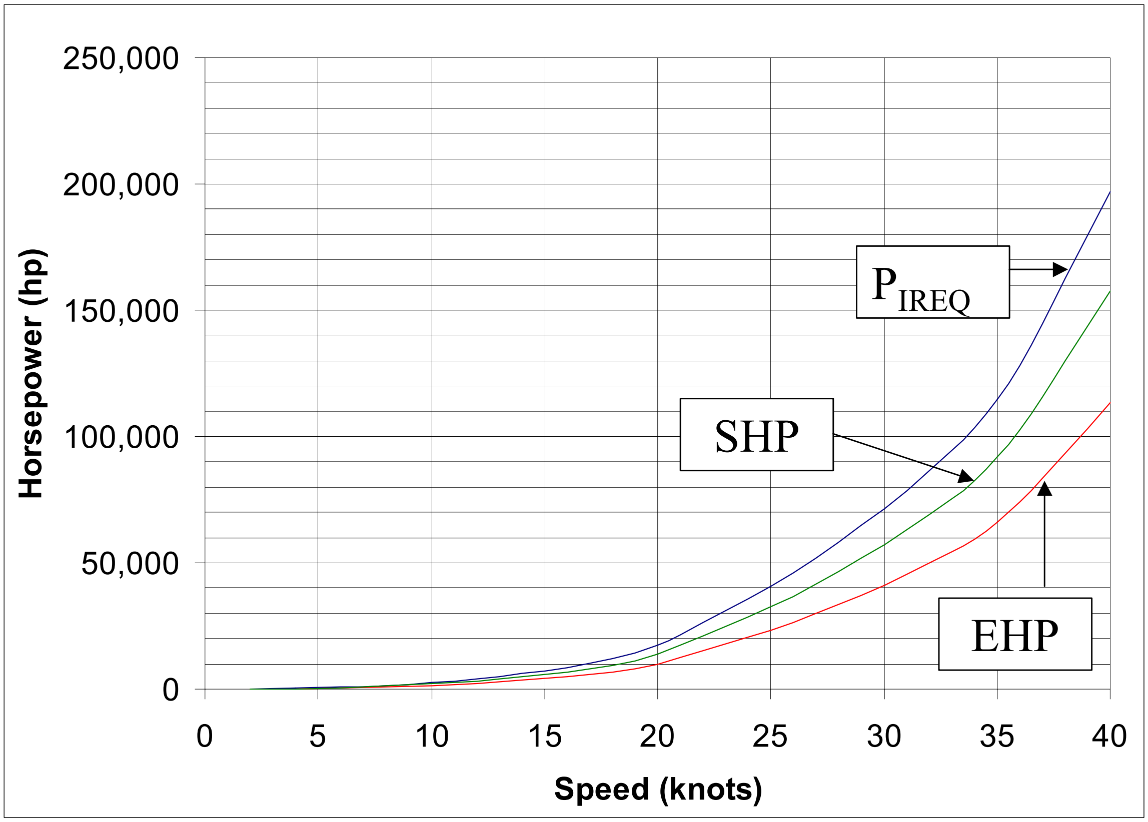

Figure 12: Required Horsepower

4.1.4 Area/Volume

Using the equivalent monohull model in ASSET, longitudinal bulkheads can be inserted to separate the main hull and side hull compartments. Decks and transverse bulkheads can be located in the same manner as they would be in a monohull. Once all the decks and bulkheads are in place, ASSET calculates the available arrangeable area and volume for each compartment. The equivalent monohull is also modeled in POSSE, as it gives more reliable tankage volumes. These files are unable to provide any area information on the cross-deck, because it does not exist in the equivalent monohull. Compartment areas for the cross-deck structure can be calculated by hand due to their regular, geometric shapes.

The deckhouse available area is another matter. Since the beam of the equivalent monohull is not large enough to accommodate the large deckhouse, the deckhouse must be created in a separate file. Removing the island from the LHD 5 model in ASSET provides a large enough deck area for the superstructure. Using this model, the deckhouse available area can be calculated

The required area comes from the ASSET equivalent monohull space report. Additional requirements are added to accommodate the amphibious lift capacity. The deckhouse area requirements are taken from the deckhouse model in ASSET.

A Microsoft Excel spreadsheet is used to track the allocation of space within the ship. It uses the compartment arrangeable areas from ASSET and the tank volumes from POSSE for all the main hull and side hull compartments. The hand-calculated cross-deck compartment areas are also inserted, as well as the deckhouse areas.

4.1.5 Structural Analysis

The preliminary structural analysis is essential in determining the feasibility of such a large trimaran. There are two major areas of concern. First, like a monohull, the main hull of a trimaran will be subjected to sagging and hogging bending moments, and must have adequate longitudinal strength to withstand both. Additionally, cross-deck structure of the trimaran must be able to withstand a transverse bending moment.

The finite element analysis tool MAESTRO is the primary tool used in the structural analysis of the trimaran. It was chosen for several benefits it offers the designer. It allows the designer to create a global finite element model for preliminary structural analysis. MAESTRO is strictly a finite element analysis tool, so it can handle any type of structure. It can also perform optimization for scantlings of various structural components, which is essential in later stages of the structural design.

4.1.6 Weights

ASSET is the primary tool for the trimaran weight estimation. It can accurately predict the weights and vertical centers of gravity for SWBS groups 200 – 700. Since the ASSET model does not contain the cross-deck structure, the structural weight (SWBS group 100) is taken from the structural model in MAESTRO. The weight of the deckhouse is taken from the ASSET deckhouse file.

The weight and center of gravity of the loads comes from a variety of sources. SWBS groups F10 and F30 include the crew and effects weight, and the stores weight, respectively, and are taken from ASSET. SWBS group F20 is taken from ASSET with the exception of WF23, the aircraft weight, which is tabulated, based on the number and type of aircraft onboard. The fuel weights in SWBS group F40 are calculated based on the tankage volumes for each type of fuel. The same is true for SWBS group F50 (which includes fresh water). Finally, the cargo in group F60 includes the USMC vehicle weight and equipment weight, and is estimated based on the area and volume available.

A Microsoft Excel spreadsheet is used to track all the weights and centers of the ship. This allows accurate calculation of the lightship and full load displacements, as well as the vertical, longitudinal and transverse center of gravity.

4.1.7 Seakeeping

Predicting the motions of any ship is a very challenging task. In the case of an advanced hull form such as a trimaran, the process becomes even more difficult. Software packages such as SWAN are very useful in the seakeeping analysis of monohulls. They require significant modifications in order to model a trimaran, however. Due to the time constraint on this design study, the seakeeping analysis was performed on a more qualitative level.

The roll motions of the ship are the most difficult to predict. It is important to determine the ship's natural roll period for two reasons. Fist, waves that have an encounter frequency near the ship's roll resonance frequency can cause severe roll. Also, the roll period is an important characteristic for aircraft operations.

Equation 13 is the undamped equation for the roll of a ship.

$$I_X(1+X_A)\ddot{\phi} + \Delta\overline{GM}_T\phi = 0 \tag{13}$$

Where: X_A is the added mass coefficient for roll

I_x is the moment of inertia about the x-axis

$\ddot{\phi}$ is the angular acceleration

$\Delta GM_T\phi$ is the righting arm converted to radians

The moment of inertia can be replaced by the relationship in equation 14.

$$I_x = mk_X^2 \tag{14}$$

Where: m is the mass of the ship

k_x is the transverse radius of gyration

The mass of the ship is equal to the displacement (Δ) divided by the gravitational constant (g). Substituting these values into equation 13 and rearranging the terms yields equation 15.

$$\ddot{\phi} + \frac{\Delta\overline{GM_T}}{\frac{\Delta}{g}\cdot(1+x_A)\cdot k_X^2}\cdot\phi = 0 \tag{15}$$

This is the equation for simple harmonic motion, where the natural frequency (ω_n) is described by equation 16.

$$\omega_n^2 = \frac{g\cdot\overline{GM_T}}{(1+x_A)\cdot k_X^2} \tag{16}$$

Finally, equation 17 describes the roll period of the ship.

$$T_{n\phi} = 2\pi k_X\sqrt{\frac{1+x_A}{\overline{GM}_T}} \tag{17}$$

These are general calculations that should be valid for any type of ship, not just a monohull. Similar calculations can be done to determine the natural pitch period of the ship. [9] A MathCad worksheet is used to perform the roll period calculations.

The main goal of the seakeeping analysis is determining how the ship will behave in waves. Poor seakeeping characteristics can lead to mission degradation in high sea states. Due to the lack of software available to predict the motions of a trimaran, a qualitative comparison was performed in this area. Researchers at the University College of London (UCL) have done a significant amount of research on trimaran design. This analysis relies heavily on their studies, particularly the work of Junwu Zhang in 1997 [10]. His work became the foundation for the design of the RV Triton.

Using a seakeeping program called GODDESS, he compared the performance of a trimaran and monohull of similar displacements in head seas. Table 14 shows the basic characteristics of each ship. Figures 13 - 16 show the graphical results of the study.

Table 14: Characteristics of Monohull and Trimaran [10]

Parameter	Monohull	Trimaran (center hull)
Length (ft) (L)	410.0	485.4
Beam (ft) (B)	48.4	34.5
Draft (ft) (T)	14.1	16.4
L/B	27.8	46.1
B/T	11.3	6.8
Displacement (LT)	4000	4000

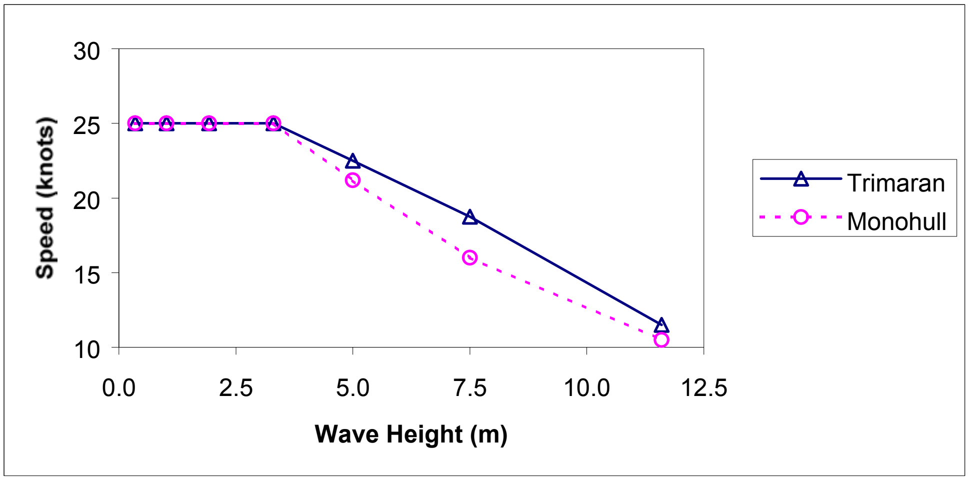

Figure 13: Speed Reduction Due to Bow Slamming [10]

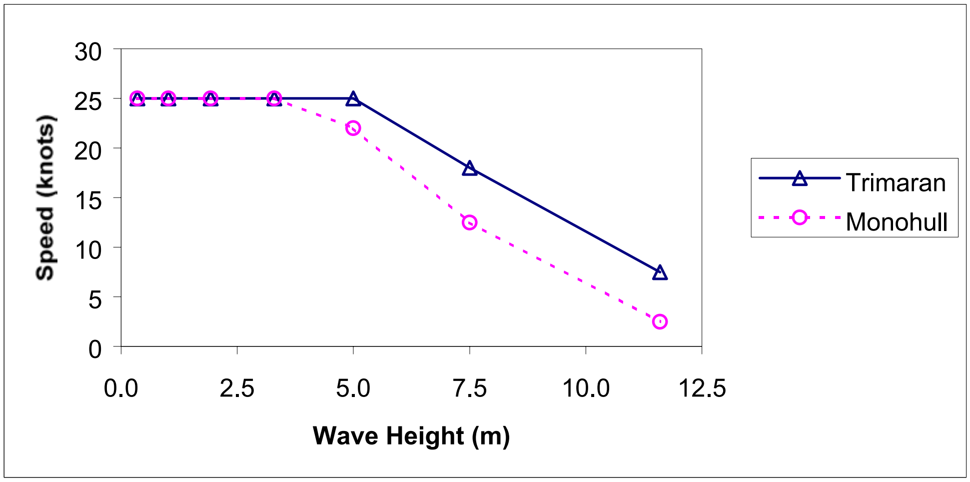

Figure 14: Speed Reduction Due to Deck Wetness [10]

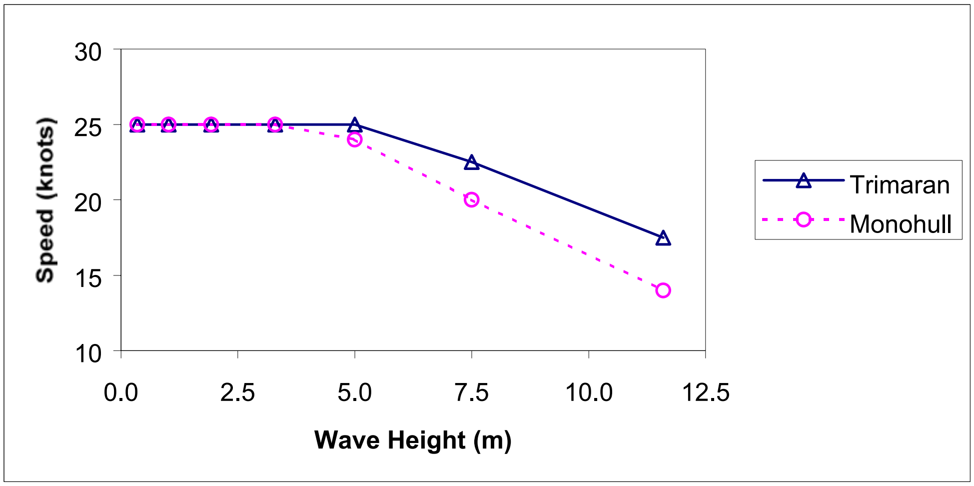

Figure 15: Speed Reduction Due to Bridge Deck Acceleration [10]

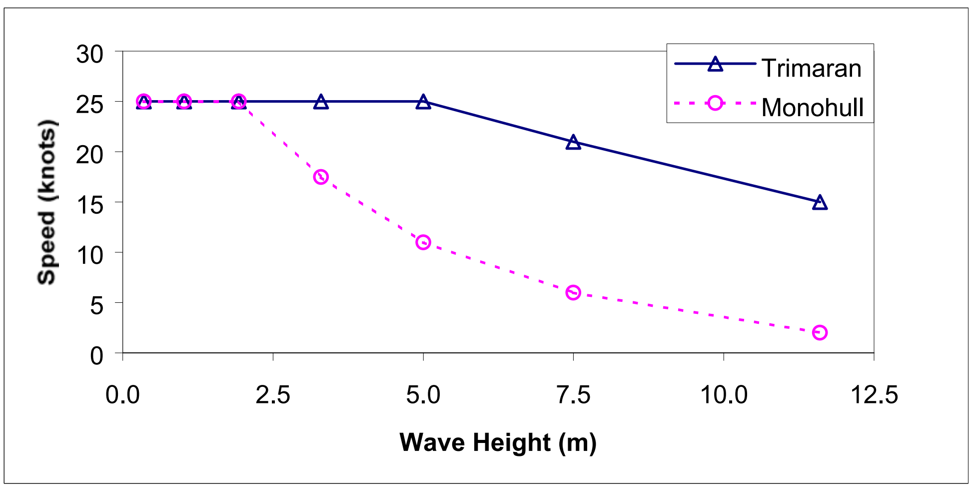

Figure 16: Speed Reduction Due to Flight Deck Acceleration [10]

As expected, the long center hull of the trimaran allows it to maintain speed in higher sea states than the monohull. This is most obvious in Figure 16, which looks at the flight deck acceleration criteria. The trimaran performs better in this area partly because of its longer main hull, but also because the flight deck is located closer to the ship's center of buoyancy [10].

4.2 Design Definition

The final trimaran design is a result of several iterations using the methods described in section 4.1. The following sections describe the major aspects of the design.

4.2.1 Ship Geometry

The required size of the flight deck constrains the basic dimensions of the ship. The platform trade-off study determined that the complement ship should carry 7 aircraft, all of which were assumed to be MV-22s. This number was later revised to include 6 MV-22s, which is half the MV-22 complement of the ARG, as well as 2 smaller SH-60s for search and rescue. A fully-loaded MV-22 requires a 75-ft strip for takeoff in the in the worst case wind-over-deck scenario. Additionally, the width of the strip must be at least 75 ft. This gives the aircraft the minimum required clearance from the deck-edge and any structure [11].

Since the complement ship is much smaller than an LHA or LHD, the aircraft will be much closer to the water. Therefore, the design team required that sufficient hangar space exists to contain all aircraft simultaneously. A separate hangar deck would provide the required area, but would also constrain the internal arrangements of the ship. Also, the elevators required to move the aircraft would take up more space and add weight to the ship. Since a trimaran has a large deck area, the decision was made to create a large hangar on the flight deck. The estimated area for this hangar is 12,000 ft^2, and the rest of the deckhouse structure can be built on top of the hangar.

Vehicle parking area is another consideration in sizing the ship. Since the trimaran does not have a well deck, the only way to embark and debark vehicles is by airlift, or possibly a crane. For this reason, the vehicle parking area must be easily accessible from the flight deck. Again, stowing the vehicles on the flight deck eliminates the need for large ramps or elevators for the vehicles. Figure 17 shows the notional flight deck layout. Overall dimensions for the trimaran are derived from this figure.

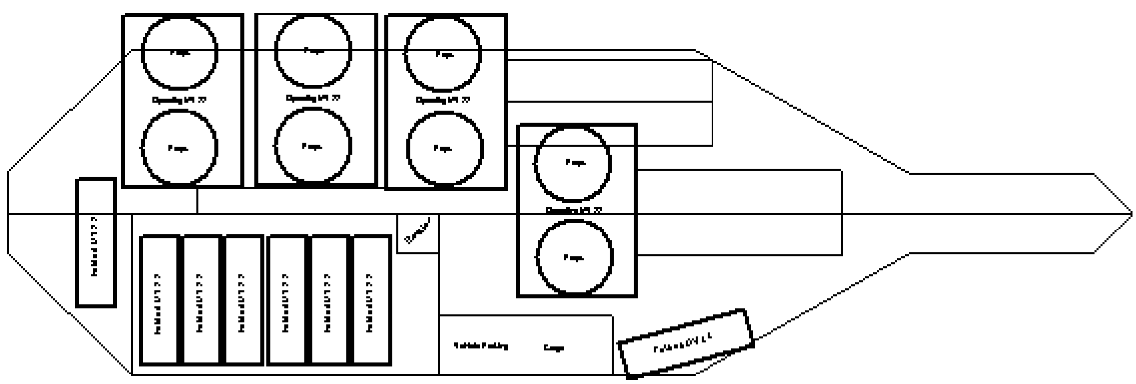

Figure 17: Notional Flight Deck Layout

The dimensions of the main and side hulls depend on the size of the flight deck. A main hull of 550 ft should allow sufficient flight deck area for the operation of MV-22 aircraft. Additionally, the overall beam must be 160 ft to accommodate the hangar as well as the MV-22 strips. Since very few guidelines exist concerning trimaran hull design, the length-to-beam ratios (L/B) of Triton were used as a reference point. Using the main hull L/B of Triton of 14 [12], the beam of the main hull for the LHA(R) becomes 40 ft.

While no stability criteria exists for trimaran warships, it is estimated that the side hulls must be at least 40% of the main hull length in order to maintain adequate stability in damaged

conditions. Longer side hulls also create a larger flight deck area, but increase the resistance of the ship. For the LHA(R), the side hulls are 50% of the main hull length, or 275 ft. A L/B of 23, similar to that of Triton, leads to a beam of 12 ft. Table 15 lists several important hull characteristics.

Table 15: LHA(R) Complement Ship Hull Characteristics

	Overall	**Main Hull**	**Side Hull**
Length (ft)	550	550	275
Beam (ft)	160	40	12
Draft (ft)	20	20	10
Depth at Station 10 (ft)	40		

Using the basic dimensions of the trimaran, the hull offsets are generated using TriSet, which runs the Trihull program. Figure 18 shows as isometric view of the offsets for the three hulls of the LHA(R).

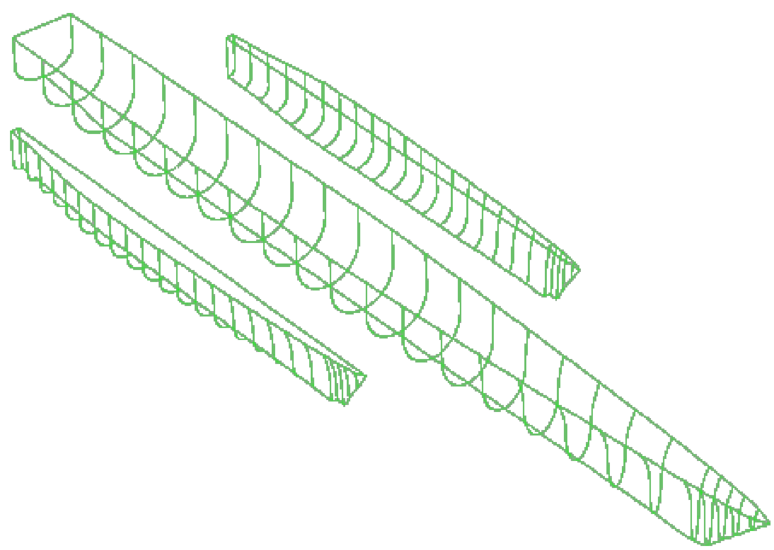

Figure 18: Isometric View of Hull Offsets

4.2.2 Combat Systems

The C4ISR system for the LHA(R) complement ship is centered around the ability to maintain real-time connectivity with the other ARG ships as well as Marine Corps elements ashore. Communications equipment includes the AN/WSC-3, AN/USC-38, and a satellite

communications system. The WSC-3 supports 7000 channels at 25-kHZ intervals and is the Navy's standard UHF satellite communications terminal and line-of-sight radio transmitter/receiver. The USC-38 establishes and controls EHF communications. Additionally, HF/VHF whip antennas are mounted along the deck edges and on the superstructure.

It is assumed that the ARG will deploy with a surface combatant that is capable of providing area defense for the entire ARG and fire support for the Marines ashore. For this reason, the radar and weapons systems on the LHA(R) complement ship are minimal. One of the primary functions of the ship is helicopter operations. The AN/SPS-49 radar provides 2D air coverage out to 220 nm, allowing the ship to effectively track and control its embarked aircraft. It is an L-band radar that provides automatic detection and reporting of targets within its surveillance volume. This is supplemented by the AN/SPN-46 Precision Landing System, which supports flight deck launch and recovery. It is a dual-channel automatic aircraft landing system with three operating modes, automatic, semiautomatic, and manual. Course corrections are transmitted to the aircraft over Link 4A. The ship also carries Tactical Air Navigation (TACAN) and Identification Friend or Foe (IFF) antennas.

The surface search radar for the LHA(R) complement ship is the AN/SPS-67, complemented by the AN/SPS-64 navigation radar. The combination of these radars provides 360 degree, unobstructed coverage, and ensures an adequate surface picture.

Since the surface combatant provides an area defense capability, the LHA(R) complement ship has only a few self-defense weapons. These include a pair of Mk 15 Phalanx Close-in Weapons Systems (CIWS), as well as a pair of Rolling Airframe Missiles (RAM). These provide point defense gun and missile systems, and are arranged such that the ship has 360-degree coverage. The RAM has a range of 5 nm, and is a fire and forget weapon, controlled initially by the signal of the target, then switching to infrared. The CIWS uses a 20-mm machine gun with penetrating rounds to destroy incoming missiles at a range of up to 6000 yards. The ship also carries 25-mm machine guns for defense against small boats.

4.2.3 Propulsion, Electrical and Auxiliary Systems

The propulsion plant was selected based on a qualitative analysis. The large beam of the trimaran creates concerns with respect to its maneuvering characteristics. Specifically, it could be difficult to turn a ship of this size. Placing propulsors in the side hulls would provide thrust far from the centerline, allowing the ship to twist. The beam of the side hulls is not large enough to accommodate a prime mover, however. The logical conclusion is to locate the prime movers in the main hull, with electric motors driving the propulsors in the side hulls. Since the side hulls have a very shallow draft, podded propulsors are installed to allow use of a larger propeller. Podded propulsors are also used in the main hull because they require no shafting through the aft compartments of the ship and eliminate the need for separate rudders. Additionally, due to the electrical reversal capability, reversing turbines, gears or controllable-reversible pitch propellers can be eliminated. The presence of electric drive on the ship naturally leads to an integrated power system (IPS). Based on previous IPS design work in the U.S. Navy, specifically that of the LHD 8, gas turbines are selected as the prime movers. The GE LM2500+ is selected based on its commonality with other designs, as well as its power and maintainability. The LM2500 series gas turbine engines have proven to be well suited to shipboard applications due to their compact size, light weight, high power density, and high reliability [13].

The IPS configuration is developed in the ASSET equivalent monohull model, with guidance from CDR John Amy. The ship is broken into several zones (the exact number will be

determined in a more detailed analysis), as shown in Figure 19. The LM2500+ gas turbine generators have direct power connections to the propulsion modules and power conversion modules (PCM). Each propulsor consists of an AC, water-cooled motor that is directly connected to the propeller. The motors can be scaled based on the ship's power requirement. The PCMs provide electrical power to the ship through a DC Zonal Distribution System (DC-ZEDS). Two additional gas turbine generators (DDA 501-K34) are installed for use inport and during emergencies. The use of these generators is consistent with current surface combatants.

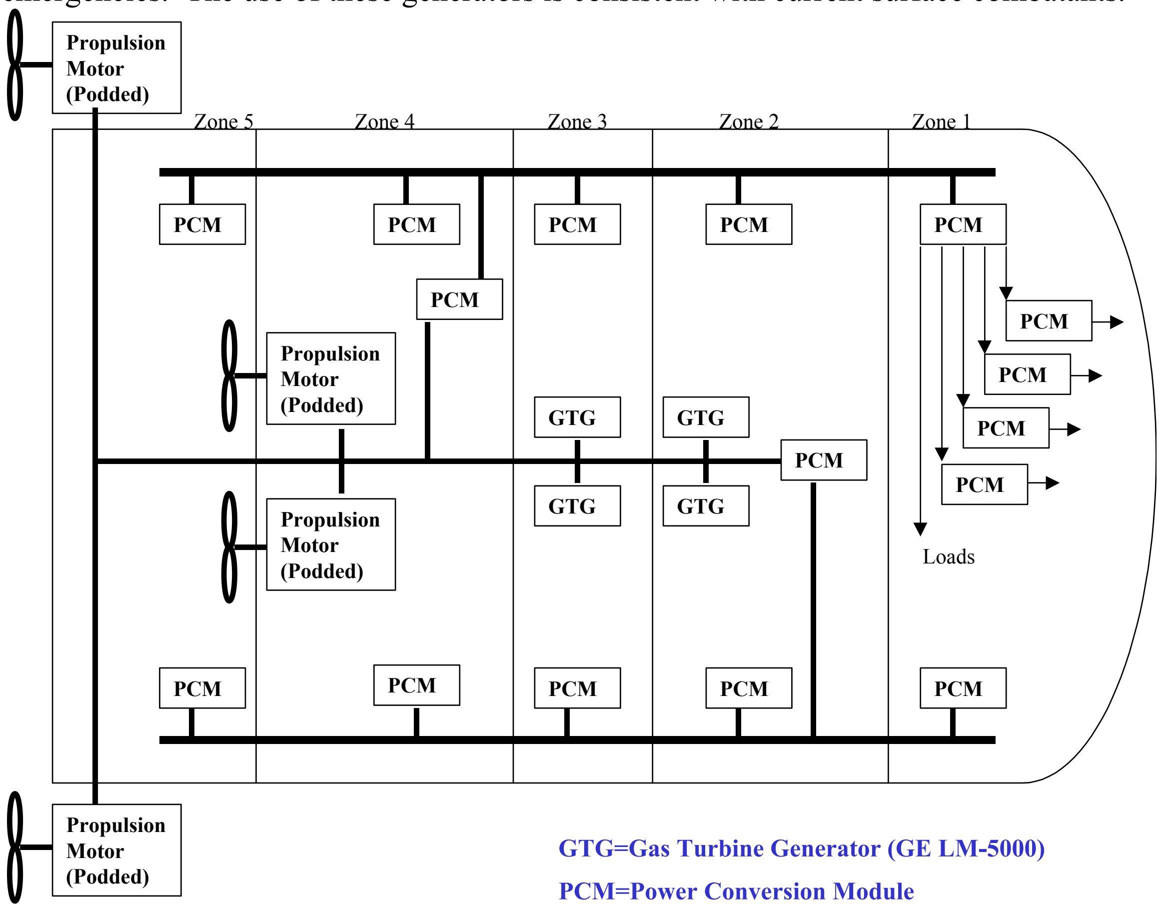

Figure 19: IPS Layout

Four LM2500+ gas turbines, each rated at 26,100 kW (35,000 hp), provide a total power of 104,400 kW. The ship's margined electrical load at battle conditions is not expected to exceed 7,500 kW, which leaves no less than 96,900 kW (130,000 hp) available for propulsion. The installed power required curve in Figure 12 (Section 4.1.3) shows that with an installed power of 130,000 hp, the trimaran can achieve a sustained speed of greater than 36 kts.

4.2.4 Manning

Due to the complexity of the manning of any ship, the design team did not undertake a detailed investigation of the ship's manning. The crew size for the LHA(R) complement ship is estimated based on the LPD 17 and DDG 51. The LPD 17 requires a crew of about 465, while the DDG 51 requires a crew of about 300. The integrated propulsion and electrical systems allow the required manning in the LHA(R) complement ship engineering department to be less

than either of the baseline ships. Additionally, the minimal combat systems on the ship require far fewer personnel than either the LDP 17 or DDG 51. The LHA(R) complement ship does need a significantly larger flight deck crew than either baseline ship, however. It is also assumed that a few of the manpower reduction strategies used in the DD(X) program will be applied to the LHA(R). The final estimate is a crew of 25 officers and 200 enlisted personnel for the trimaran. The ship also has accommodations for 200 Marines.

4.2.5 Arrangement

The first consideration in the internal arrangement of the ship is the location of the decks and bulkheads. Figure 20 provides a cross-section of the ship, showing the location of all the decks. The crossdeck structure provides a large amount of arrangeable area, which compensates for the lack of arrangeable area in the ship's long, narrow hulls.

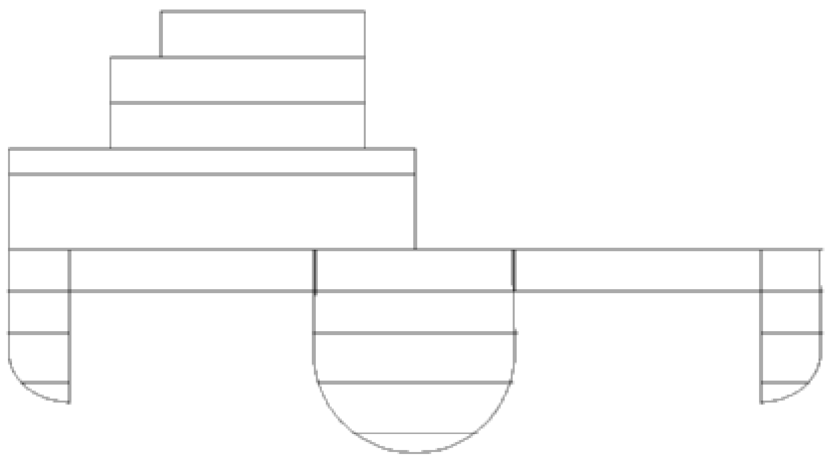

Figure 20: Cross Sectional View of Trimaran

The location of the transverse bulkheads depends largely on the floodable length of the ship, as well as the required length of the machinery rooms. Since the ship is using IPS, the location of the machinery rooms is not constrained by shafting. The floodable length of the ship can be investigated using the equivalent monohull model in ASSET, and further analyzed using SHCP, as will be discussed in Section 4.2.7.

Figure 21 shows the topside arrangement of the ship. It includes the flight deck features of Figure 17, along with the combat systems equipment discussed in Section 4.2.2. The CIWS and RAM mounts are located such that each pair of systems provides nearly 360-degree coverage. All radars and most of the communications equipment is located on the mast. The boats and a crane are located on the starboard side so they do not interfere with flight operations. The longitudinal location of the bridge leads to concerns about the line-of-sight over the bow. Directly over the bow, the minimum visible range is about 200 ft at the waterline. Since the bow is so fine, however, there is much less of a blind spot on either side. The same line-of-sight concerns present a problem to the port side, as well, where the minimum visible range at the

waterline is again about 200 ft. This would create an awkward situation if the trimaran were to conduct an underway replenishment on its port side. For this reason, as well as to maintain a clear flight deck, there are two refueling stations located on the starboard side. The port side does have some refueling capability to facilitate refueling in port.

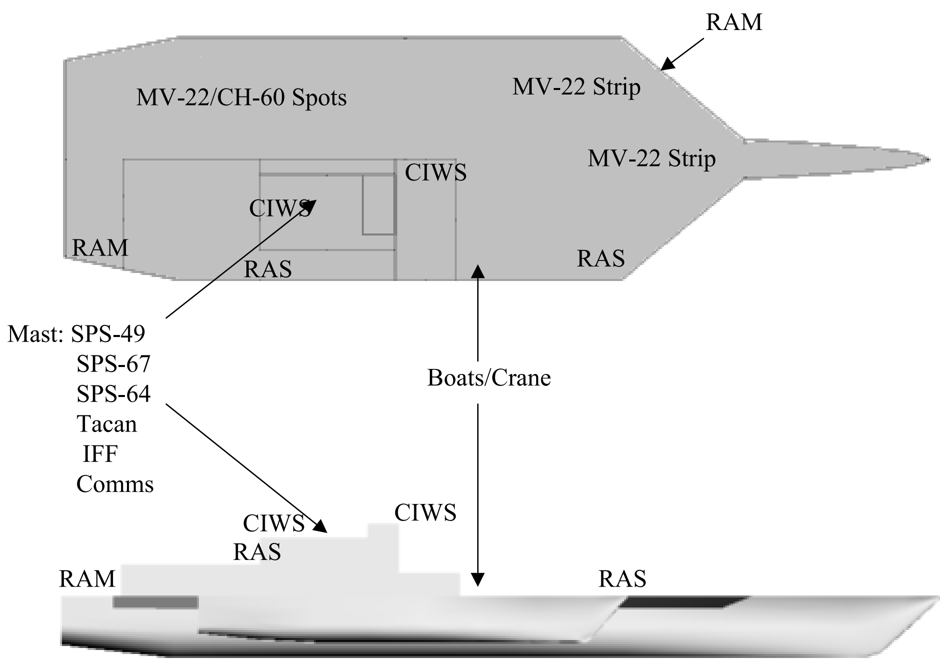

Figure 21: Topside Layout

The lower compartments of the ship are dedicated to tankage. The location of the tanks is shown in Figure 22. The ship has a clean ballast system, so it requires several seawater ballast tanks, which are located as far forward and aft in the main hull as possible to allow better trim control in all load conditions. Also, the port side hull has significantly more tankage than the starboard side. This is to offset the weight of the deckhouse on the starboard side hull. The presence of seawater ballast tanks in the port side hull is essential to maintaining a minimal heel angle at the minimum operating condition.

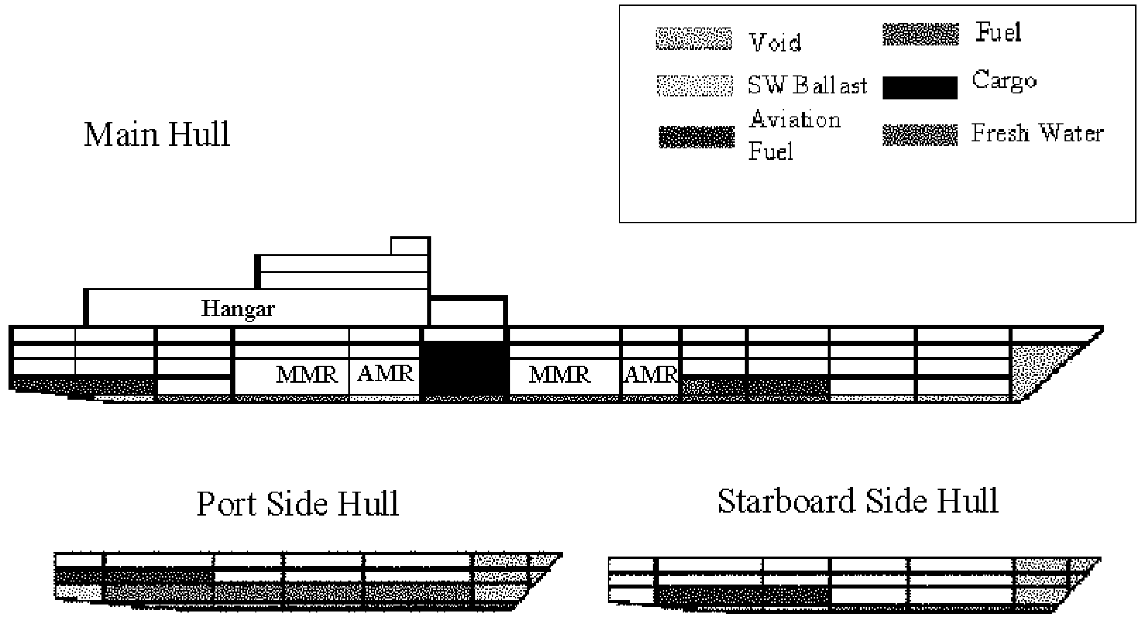

Figure 22: Tank Allocation

Figures 23 - 26 show the plan view of each deck in the trimaran, as well as the major equipment and systems in the space. On the flight deck level, the deckhouse consists of the hangar and vehicle parking area. Additionally, a cargo elevator is located inside the vehicle area, allowing the Marines to stage their equipment in an enclosed area prior to loading it onto the aircraft. In an effort to keep rest of the deckhouse small, it contains only the essential elements, mainly combat systems equipment.

The cross deck provides a large arrangeable area near the ship's center of buoyancy. The cross deck includes a large Combat Information Center (CIC), as well as a Command Center for the embarked Marines. The passageways between this area and the troop berthing spaces are wider than the standard 36-in clear width to allow easier transit by troops in combat gear. The officer and CPO living spaces are located on the cross deck, along with some troop and berthing compartments. The wardroom, mess decks, and galley are also on this deck. The small spaces in the side hulls are almost exclusively used as storage spaces, as are the very small spaces in the bow.

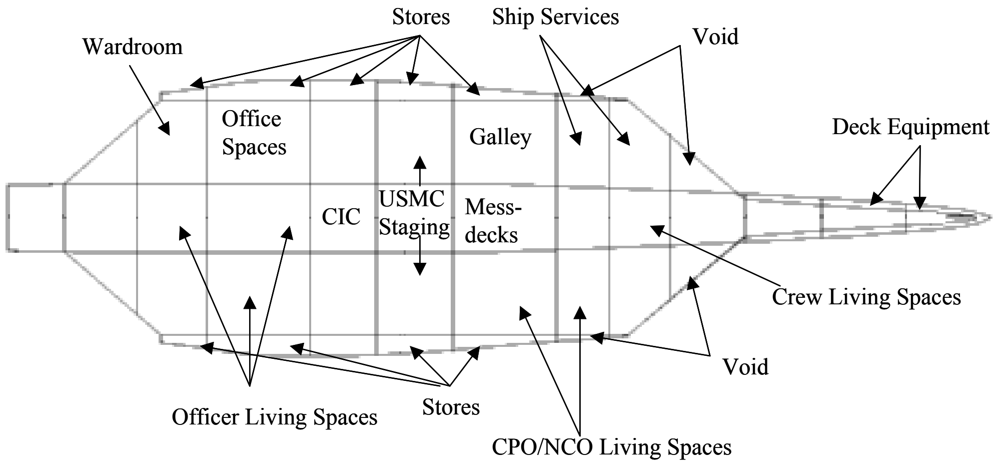

Figure 23: Cross-deck/DC Deck Allocation

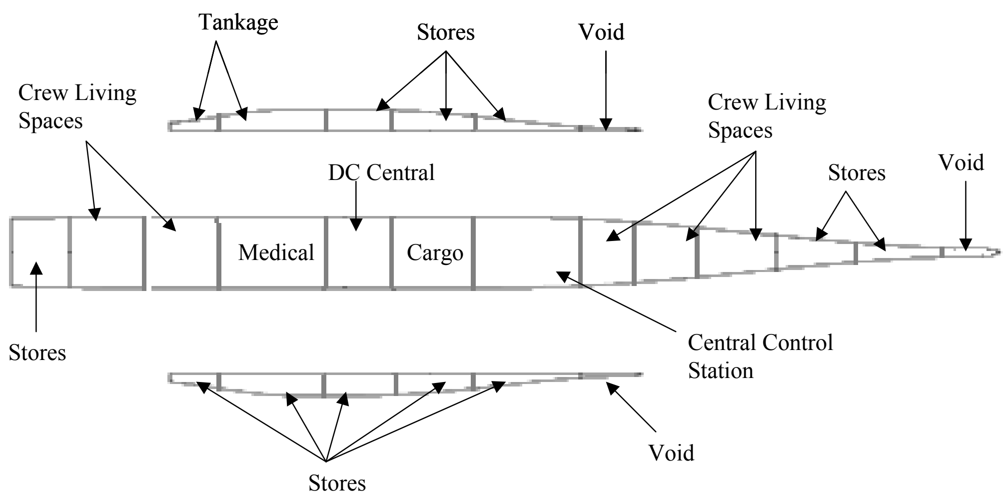

Figure 24: 3rd Deck Allocation

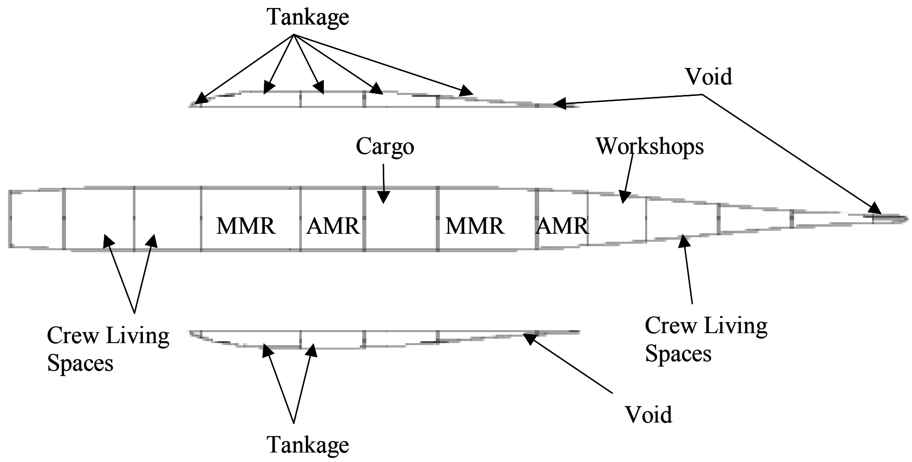

Figure 25: 4th Deck Allocation

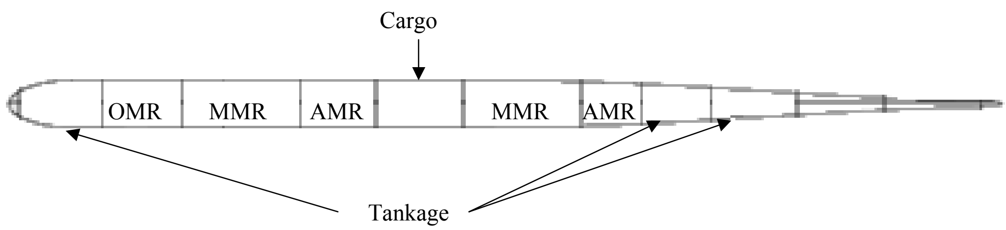

Figure 26: 5th Deck Allocation

In order to facilitate selective offload, while minimizing the number of cargo elevators, the cargo spaces are aligned vertically between the engine rooms. A single elevator on the starboard side of the ship services all the cargo spaces. The staging areas on the cross deck and in the vehicle parking area provide space to organize equipment prior to moving it to the flight deck.

4.2.6 Structural Design

The purpose of the preliminary structural analysis is to determine if the LHA(R) complement ship is structurally feasible, based on typical U.S. Navy design practices. The structural design of a trimaran is similar to a monohull longitudinally, but also requires an analysis of the transverse bending moments.

Since there are no existing standards specifically created for the trimaran hull form, the monohull standards listed in Table 16 are considered. These represent accepted and proven criteria that must be met by the designer of the vessel. In order to deviate from these design standards, significant improvement of the mission performance must be demonstrated and approved.

Table 16: Structural Design Standards

Standard	Area	Description
DDS 100-1	Structural strength	Reinforcement of Openings in Structure of Surface Ships, other than protective plating
DDS 100-2	Structural strength	Opening in Decks and Bulkheads for stuffing Tubes and Pipes
DDS 100-4	Structural strength	Strength of Structural members
DDS 100-5	Structural strength	Strength of Glass Reinforced Plastic Structural Members: Part I-Single Skin Construction
DDS 100-6	Structural strength	Longitudinal Strength Calculation
DDS 100-7	Structural strength	Structure to Resist Weapons Firing Effects
DDS 072-1, 150-1	Shock	Structure to Resist Shock Loads
DDS 072-2	Nuclear Blast	Structure to Resist Nuclear Blast Loads

4.2.6.1 Longitudinal Strength

The primary hull girder bending moments are estimated using a simple method developed by Dinsenbacher and Sikora [14]. This method is based on a curve fit of design bending moments from 13 U.S. Navy destroyer and frigate hull forms. Equations 18 and 19 are the regression equations for the hogging (M_{Bhog}) and sagging (M_{Bsag}) bending moments, respectively. In both equations, the length (L) and beam (B) are in ft, and the bending moment is in lton-ft. The standard deviation of the data from the 13 ships is +/-10% for the hogging moment and +/-8.5% for the sagging moment, indicating good curve fits in both cases. Additionally, the overall peak-to-peak bending moment has a standard deviation of +/-4%.

$$M_{Bhog} = -0.000457 \cdot L^{2.5} \cdot B \qquad (18)$$

$$M_{Bsag} = 0.000381 \cdot L^{2.5} \cdot B \qquad (19)$$

In addition to the primary bending moment, the scantlings are sized to resist slamming, hydrostatic heads, green seas, blast and live loads. Tables 17 and 18 and Figure 27 describe each of these loads. In each case, the live load and slamming load are combined to create the highest resultant loading. It should be noted that the slamming load does not occur simultaneously on the entire surface. Instead, it is a small, traveling load acting on only part of the structure at a

time. For this reason, the design load on the longitudinal stiffeners is assumed to be one-half of the load acting on the plating. Similarly, the design load on the transverse frames is assumed to be one-quarter of the load acting on the plating

Table 17: Load Case 1

Loading Condition	Type	Value
Primary hull load	Hogging	1.7E+05 (lton·ft)
Secondary deck load	Hydrostatic Pressure	19.8 (ft)
Tertiary deck load	Live Loads Green Seas Slamming	2.75 (ft) 4 (ft) 7 (ft)

Table 18: Load Case 2

Loading Condition	Type	Value
Primary hull load	Sagging	1.4E+05 (lton·ft)
Secondary deck load	Hydrostatic Pressure	19.8 (ft)
Tertiary deck load	Live Loads Green Seas Slamming	2.75 (ft) 4 (ft) 7 (ft)

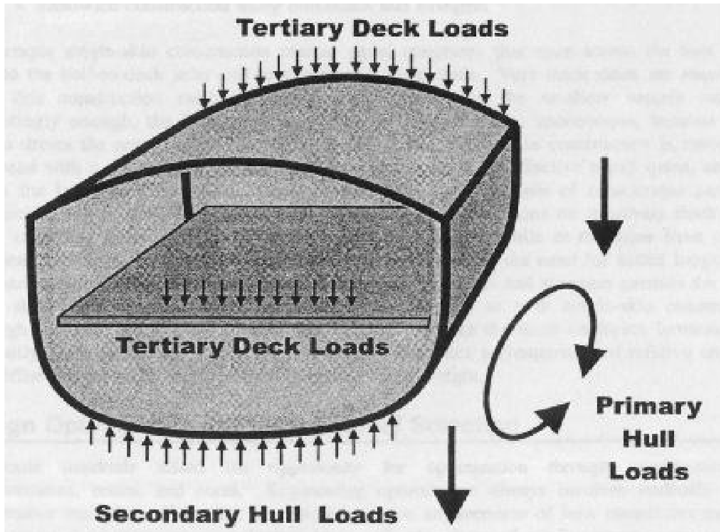

Figure 27: Primary, Secondary and Tertiary Loads

4.2.6.2 Transverse Strength

There is very little guidance for the transverse strength of ships with multiple hulls. The worst-case transverse bending moment of the ship occurs when one of the side hulls is completely out of the water. To simulate this condition, the cross deck-side hull structure is modeled as a cantilever supported by the main hull. The secondary and tertiary loads listed in Tables 17 and 18 also apply to the transverse condition. Additionally, the weight of the deckhouse and off-center tanks is included in the analysis.

4.2.6.3 Modeling

MAESTRO was used to perform finite element analysis based on the loading conditions described above. The structural design of the conceptual hull geometry is initiated by designing a midship section of the trimaran, using the dimensions of scantlings similar to that of the LHD 5. Figure 28 presents the initial model.

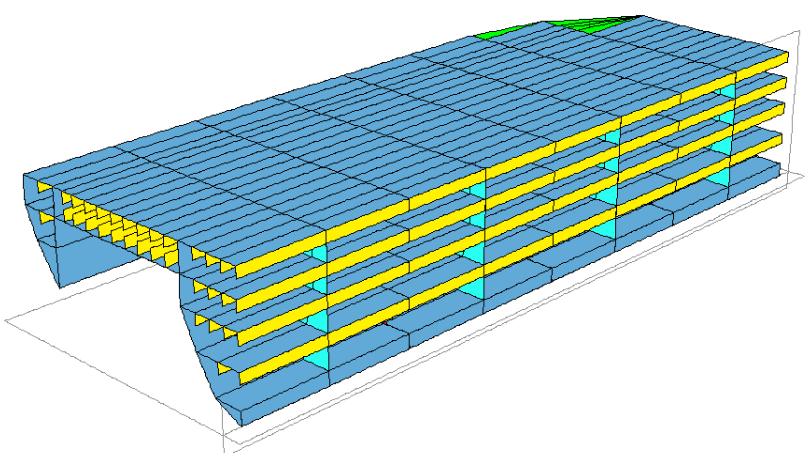

Figure 28: Midship Section Model in MAESTRO

Due to the nature of the trimaran's structural configuration, a model of the whole vessel must be evaluated. Figure 29 shows the final MAESTRO model of the trimaran.

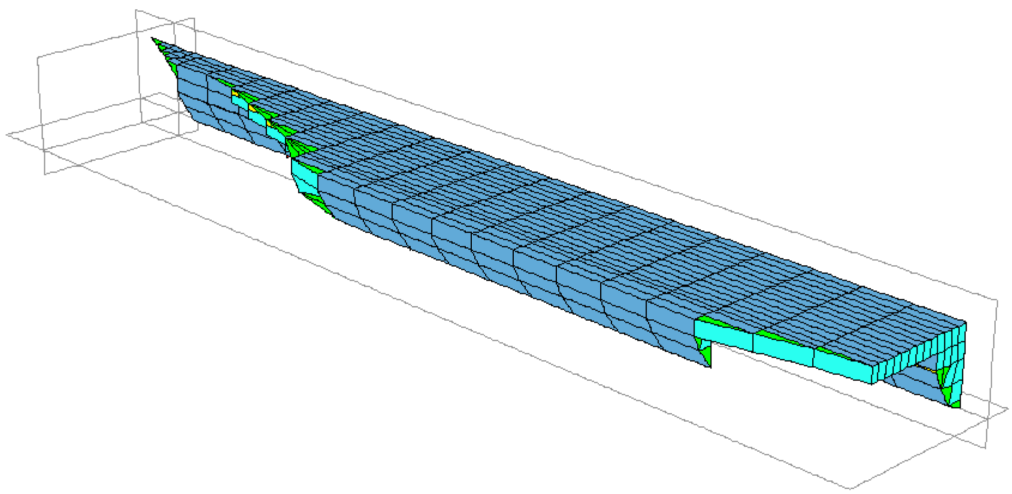

Figure 29: Finite Element Model of Trimaran in MAESTRO

4.2.6.4 Results

The results of the preliminary study indicate that the trimaran concept is structurally feasible. HS steel (yield strength = 55 ksi) is the primary material for the ship's structure. Higher strength steels are required in some highly stressed areas to minimize the weight of the ship. HY-80 steel (yield strength = 80 ksi) and HSLA 100 steel (yield strength = 100 ksi) are used in these areas. Details of the structural analysis are presented in Appendix I.

Structural details such as brackets, large openings, hangar door reinforcements, etc. have not been evaluated. Additionally, the main watertight bulkhead scantlings have not been sized, although a cursory review reveals no major concerns. Likewise, a smooth transitioning and tapering of the scantlings was deferred until the next phase of the design process.

4.2.7 Weights, Stability and Margins

Prior to conducting the stability analysis, a more detailed hydrostatic analysis was performed using SHCP. The sectional area curves of the main hull are shown in Figure 30. In this figure, the length of the ship is on the x-axis and the sectional area is on the y-axis. Figure 31 shows the sectional area curves of the trimaran, including both the main and side hulls. The presence of the side hulls creates a noticeable increase in area over their length.

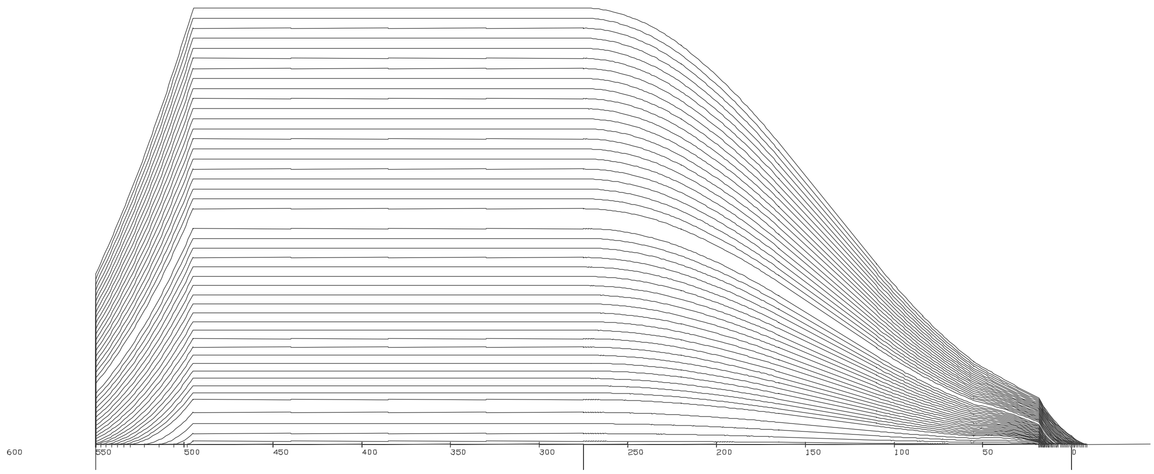

Figure 30: Sectional Area Curves of Main Hull

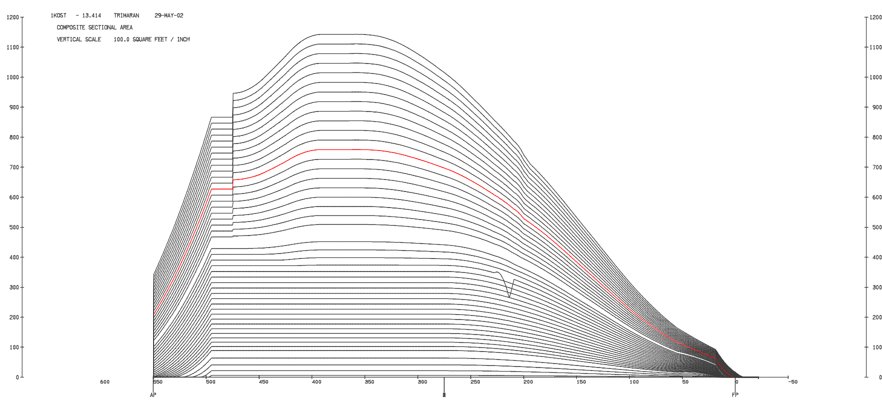

Figure 31: Trimaran Sectional Area Curves

The curves of form for the trimaran are shown in Figure 32. The impact of the side hulls can be most clearly seen in the transverse metacentric height curve. The side hulls begin to immerse at a depth of approximately 13 ft, increasing the moment of inertia of the waterline plane about the longitudinal centerline. This, in turn, greatly increases the metacentric height, causing the dramatic change in slope. A change in slope can also be observed in the tons-per-inch immersion (TPI) curve at approximately the same draft, due to the added submerged

volume of the side hulls. The other curves do not exhibit a noticeable change due to the side hulls.

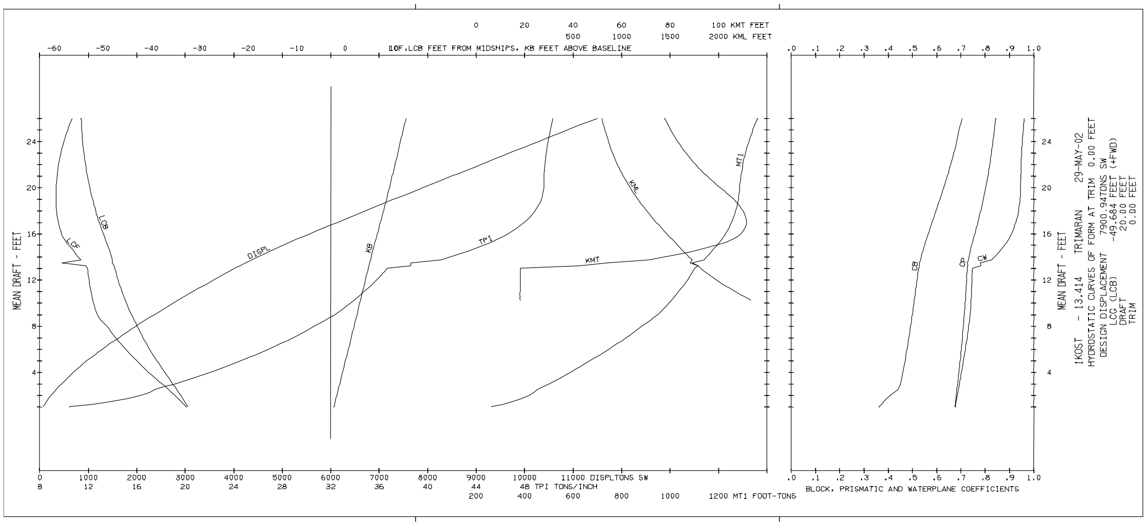

Figure 32: Curves of Form

The weight groups of the ship were compiled in an Excel spreadsheet, as described in section 4.1.6. Table 19 summarizes the weight groups and their centers. The vertical center of gravity (VCG) is measured from the keel, while the longitudinal center of gravity (LCG) is measured from the forward perpendicular. The transverse center of gravity (TCG) is measured from the centerline, with a positive value corresponding to the starboard side. At full load, the ship has a KG of 24.3 ft, LCG of 331.3 ft (aft of the forward perpendicular) and a TCG of 0.4 ft to starboard, signifying that the ship does not list significantly to either side, and does not have any significant trim problems. In the lightship condition, the TCG is 2.7 ft to starboard, meaning that the ship would list slightly. Careful ballasting can prevent a significant list when the ship is at its minimum operating condition.

Table 19: Weight Groups and Centers

Weight Group	Weight (lton)	VCG (ft)	LCG (ft)	TCG (ft)
100	4026.5	31.9	342.7	4.3
200	1177.4	6.6	395.5	0
300	759.2	25.14	295.6	0
400	99.2	36.3	398.3	35
500	887.4	22.1	302.5	0
600	632.7	25.2	275	0
700	21.9	59.7	247.5	0
Lightship	7604.3	25.7	336.3	2.7
F00	1863.3	18.6	310.1	-9.8
Full Load	9467.6	24.3	331.2	0.4

4.2.7.1 Intact Stability

DDS-079-1 provides the standard stability criteria for U.S Naval vessels. It provides detailed criteria for both monohulls as well as advanced hull forms such as SWATH vessels, hydrofoils, and surface effect ships. Since it presents no criteria for trimarans, both the monohull and advanced hull criteria were examined, and the more conservative measures were taken in all cases.

The static stability curves for the LHA(R) complement ship and a DDG 51 are shown in Figure 33. The three curves for the trimaran represent the design full load displacement of 9,467 ltons and displacements of +/- 10% of the design displacement. This figure shows the large righting arm of a trimaran when compared to a similar displacement monohull.

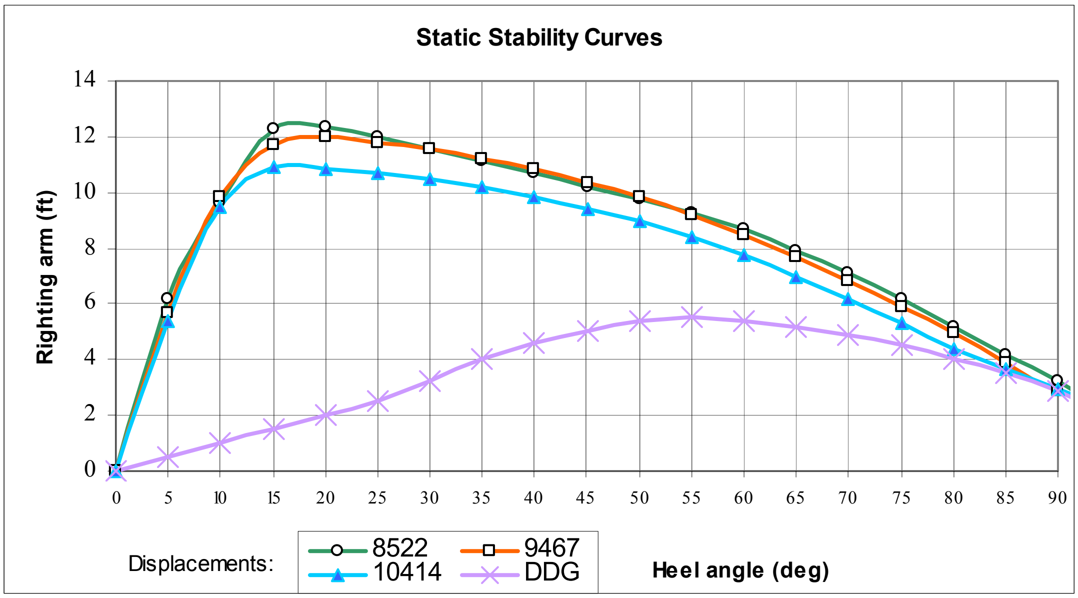

Figure 33: Static Stability Curves for LHA(R) Complement Ship and DDG 51

The intact stability analysis was completed assuming that the ship encounters high beam winds while already sustaining up to 25 degree rolls. The following conditions are assumed in order to examine the stability of the ship:

a. Wind speed = 100 kts
b. Roll back angle = 25 degrees
c. Wind heeling arm = (add eqn)

In order to pass the DDS-079-1 criteria, the heeling arm at the intersection of the righting arm and heeling arm curves may not be greater than 6/10 of the maximum righting arm. Additionally, the dynamic reserve stability ratio must be greater than or equal to 1.4. Figure 34 shows the righting arm curve under these conditions. The ship passes both criteria.

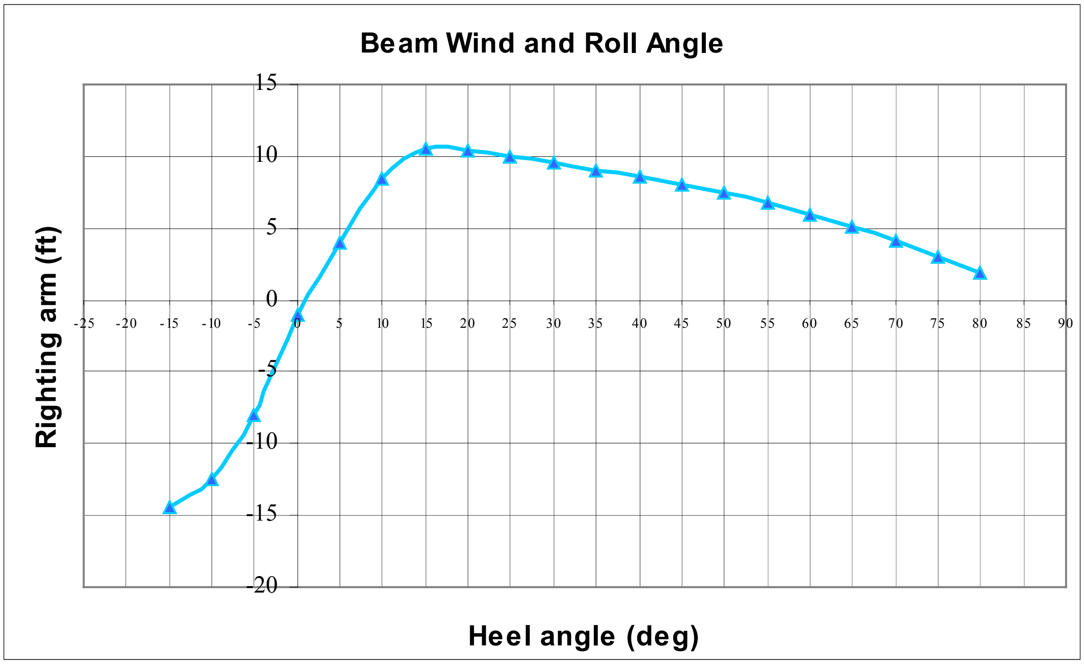

Figure 34: Intact Stability in Beam Winds

4.2.7.2 Damaged Stability

The U.S. Navy DDS-079-1damaged stability criteria require that a warship greater than 300 ft in length withstand a shell opening of 15% of the length of the waterline. While it could be argued that this criteria is overly conservative for a three-hulled ship where the outer hulls afford protection to the main hull, this argument ignores the real possibility of groundings and underwater explosions.

The damaged stability analysis was divided into three major cases: main hull damage only, side hull damage only, and combined main hull and side hull damage. The worst-case KG was assumed in all cases. According to DDS-079-1, the extent of the damage must be considered as follows:

a. Longitudinal extent: 15% of the length between perpendiculars
b. Transverse extent: does not cross centerline
c. Vertical extent: from the keel up without limit

<u>Case 1: Main Hull Damage</u>

In order to withstand hull damage 15% of the length of the waterline, the ship must be able to withstand flooding in three consecutive compartments. Side hull flooding is not included in the floodable length calculations. Figure 35 shows the floodable length curve for the trimaran. The worst case scenarios are damage in the forward part of the ship, or the extreme aft compartments. In the forward section, the fine bow provides very little buoyancy. Over the length of the side hulls, the ship has plenty of buoyancy, but forward and aft of the side hulls, damage could bring the ship near the margin line.

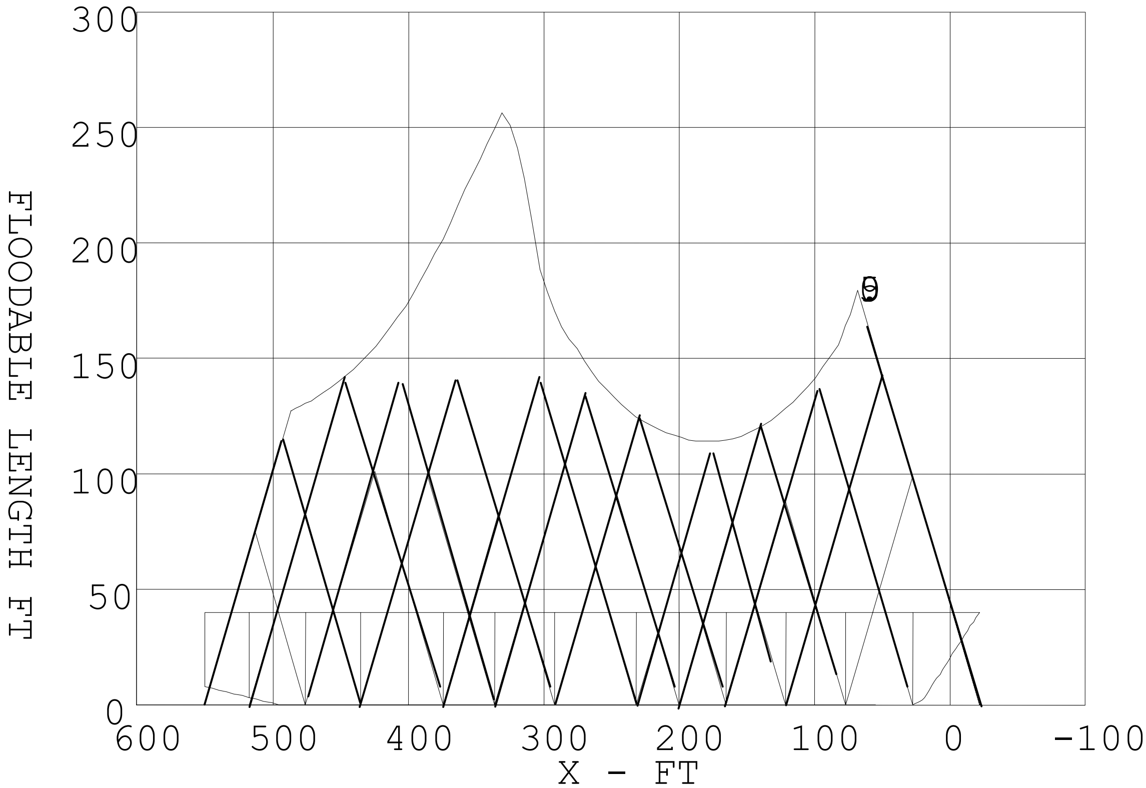

Figure 35: Floodable Length Curve

Transverse stability is also a concern when compartments are flooded. Using the three-compartment flooding criteria again, each consecutive three-compartment combination was examined, and each yielded similar results. Figure 36 shows the righting arm curves for three different conditions, flooding in the forward three compartments, flooding in the aft three compartments, and flooding in three of the midships compartments. In every case, the ship has a sufficient righting arm at all relevant angles of heel.

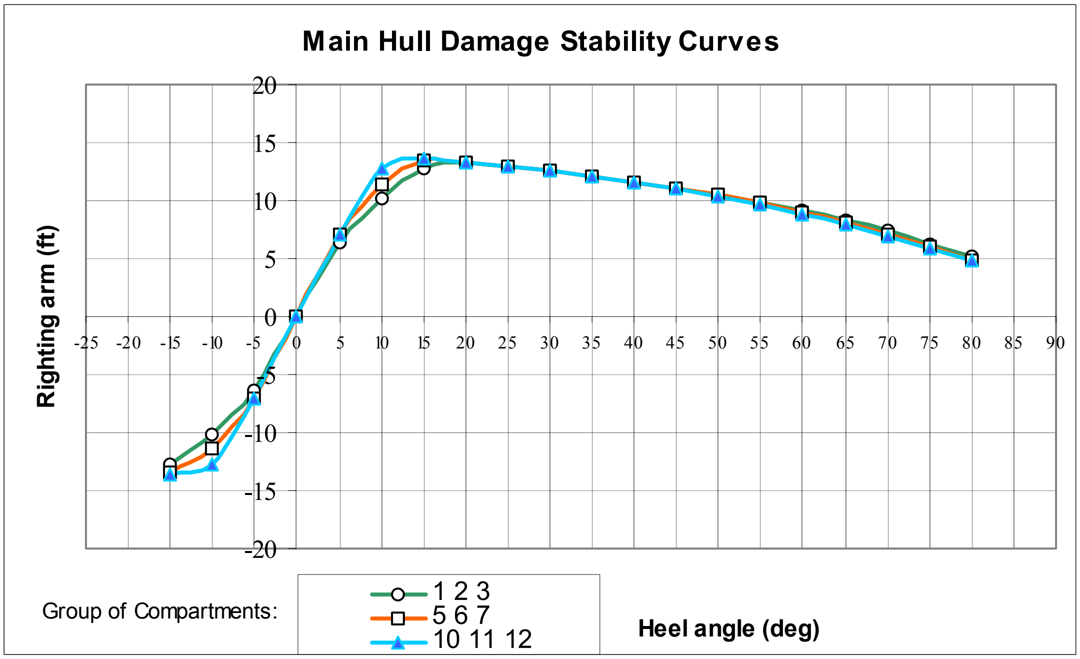

Figure 36: Righting Arm Curve for Case 1

<u>Case 2: Side Hull Damage</u>

In the absence of any established criteria for side hull flooding, the design team chose to impose the same criterion that was used for the main hull. This means that the ship must be able to withstand damage to the side hull of 15% of the total ship length. Again, this corresponds to flooding in three compartments. Each combination of consecutive compartments was analyzed and found to have adequate righting arms. Two different combinations are shown in Figure 37.

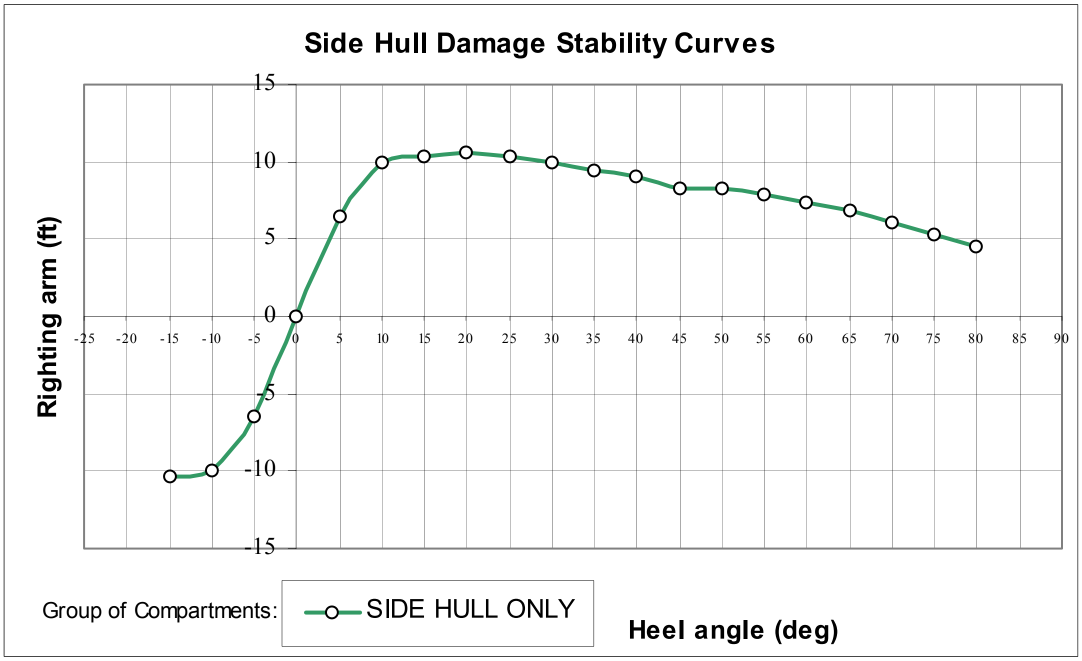

Figure 37: Righting Arm Curve for Case 2

<u>Case 3: Main Hull and Side Hull Damage</u>

The final damaged condition involves damage to the main hull and one of the side hulls. Two consecutive compartments in the main hull and two consecutive compartments in the side hull are flooded. This is the worst damaged condition studied, but the ship still maintains an adequate righting arm over the full range of heel angles, as shown in Figure 38.

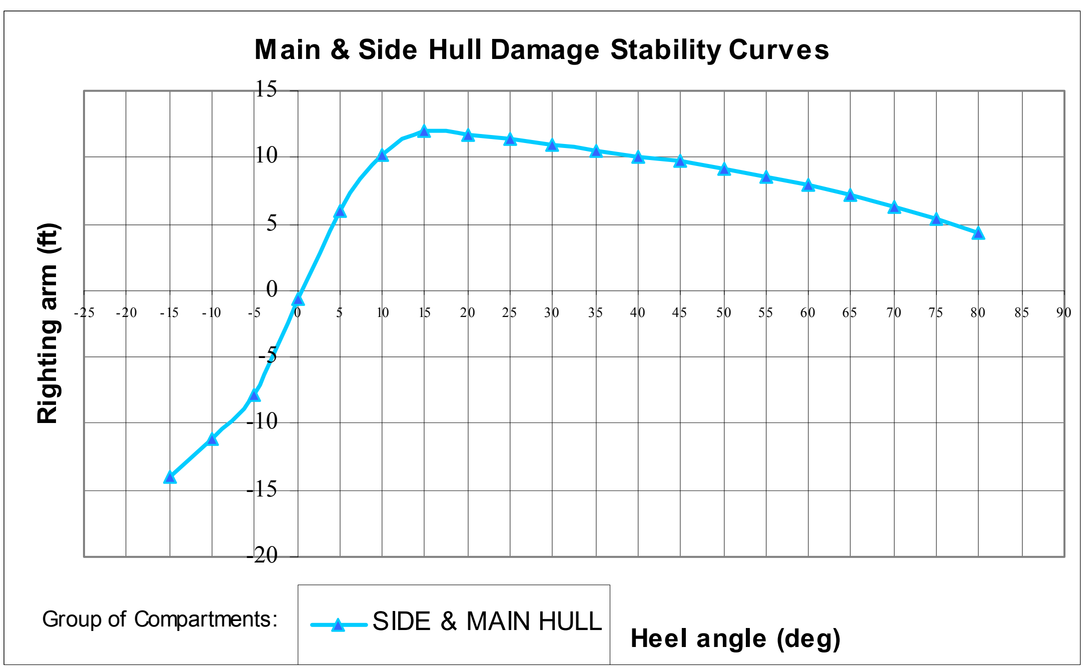

Figure 38: Righting Arm Curve for Case 3

4.2.8 Survivability and Signatures

Survivability is a function of three major elements. The first, susceptibility, refers to the degree to which the ship is open to an effective attack due to one or more inherent weaknesses. Minimizing the signatures, as well as adding advanced C4ISR capabilities and decoys can reduce the susceptibility of the ship. These measures tend to be very expensive, and are only minimally implemented on the LHA(R) complement ship.

Vulnerability deals with the characteristics of the ship that cause it to suffer degradation as a result of enemy actions. The LHA(R) complement ship has several features that help reduce its vulnerability. The side hulls provide standoff protection for the vital equipment in the main hull. The longitudinal separation of the engine rooms should protect the ship from losing all four main engines as the result of a single hit. Additionally, IPS allows the generators to be cross-connected, providing flexibility in the event of a casualty. The propulsors in the side hulls as well as the main hull should prevent a single hit from damaging all the propulsors. Finally, the two-ship LHA(R) platform is less vulnerable than a single large ship would be, due to the distribution of assets between the two ships. The loss of a single ship does not mean all the LHA(R) assets will be lost, as some are aboard the other ship.

Recoverability is the ability of the ship to regain mission effectiveness after suffering damage. The flexibility of IPS will certainly aid in recovery efforts in the event of an attack. Perhaps the most important factor in increasing the recoverability of the ship is the crew. A highly trained crew that is prepared to put its damage control training to use has a tremendous impact on the recoverability of the ship.

4.2.9 Seakeeping

The roll period of the LHA(R) complement ship is calculated using equation 17, derived in Section 4.1.7. The transverse radius of gyration of the trimaran is much greater than that of a monohull, due to the significant amount of weight in the side hulls. This tends to increase the roll period of the ship. The added mass of the trimaran is also much greater than for a monohull. The main hull of the trimaran has a similar added mass in roll as the monohull, but the when the trimaran rolls, the side hulls heave. The heave added mass term for the sidehulls is added to the added mass term of the main hull. The increase in added mass also tends to increase the roll period. Based on the SHCP model of the trimaran, as well as the analysis of weights, the $\overline{GM}_T$ of the trimaran is 21.5 ft, much greater than the monohull. The increase in $\overline{GM}_T$ serves to decrease the roll period, offsetting the increases caused by the added mass and radius of gyration terms. The roll period of the trimaran is estimated to be 11.5 s, which is similar to that of a similar displacement monohull. This roll period is low for a ship that operates aircraft to the extent of the LHA(R) complement ship. These calculations do not, however, account for appendages such as bilge keels or skegs that could be added to increase the added mass and thereby increase the roll period. This is an area that needs to be addressed in more detail in future studies.

Based on Figures 13 - 16 in Section 4.1.7, the trimaran is expected to perform better than a monohull of similar displacement in head seas. Further analysis is required in this area, as well as the performance of the ship in beam and quartering seas.

4.3 Cost and Risk

Throughout the course of this study, every effort was made to keep the cost of the trimaran low. Referring back to the selection of the LHD 8 plus a complement ship in Chapter 3 shows that if the cost of this option is increased, the option is no longer as attractive. Cost reduction strategies include the minimal combat systems suite installed on the ship, as well as a reduced crew size.

The cost of the LHA(R) platform is estimated at 1.4 times the cost of an LHD 8. this estimate comes from the weight-based MIT Cost Model. The model consists of several cost estimating ratios (CER) that have been determined based on previous experience. Unfortunately, all the previous experience is in building monohulls, not trimarans. The design team was unable to obtain any CERs that have been adjusted for trimarans because what little information exists is proprietary.

The risk involved in this project comes from several areas. First, the trimaran, like any new hull form, involves an increased level of risk, both in the performance and cost areas. Currently, the largest trimaran in existence is the RV TRITON, which, at 1200 ltons, is significantly smaller than the LHA(R) complement ship. TRITON's sea trials have been encouraging, however, showing that a trimaran has great promise as a combatant [15].

There is additional risk associated with the assumption that a surface combatant will be available to escort the ARG into hostile waters. Based on this assumption, the complement ship carries only point-defense weapons, meaning that it would have no area defense capability in the absence of the combatant. It would also be unable to provide any ship-to-shore fire support for troops ashore.

The primary function of the LHA(R) complement ship is to support the movement and employment of the ARG assets. In short, to get the troops, equipment and vehicles where they need to be, when they need to be there. The MV-22s embarked on the complement ship provide the only means of delivering amphibious assets to the objective area, meaning that a failure in this area leads to the failure of the ship's primary mission.

The risk associated with this option is somewhat mitigated by the fact that the LHD is a proven class of ships that is currently the primary platform in several ARGs.

4.4 Operation and Support

While the complement ship is approximately the same length as a cruiser, the large beam may require some special consideration in port facilities. Vehicle ramps are not carried onboard, meaning that they must be provided by the port facility, or the vehicles must be loaded or unloaded using cranes.

The endurance range of the complement ship is considerably less than that of the other ships in the ARG. This means that it must refuel more often than the other ships, either inport or underway. The LHD class does have the ability to refuel ships while underway.

5 Design Conclusions

The LHA(R) complement ship is considered a feasible design. The addition of a fourth ship to the ARG causes a dramatic increase in the ARG's flexibility. With the complement ship carrying several aircraft, the modified LHD 8 has more flight deck area, and will not be nearly as crowded. Similarly, moving cargo and vehicles to the complement ship, even a small amount, should provide extra volume on the LHD that could be used to facilitate selective offload.

The high-speed capability of the trimaran is essential to responding to emergent situation quickly. Additionally, the large amount of deck area available inherent in trimaran designs provides for a large flight deck area.

5.1 Summary of Final Concept Design

Figure 39 shows the LHA(R) complement ship. This figure does not include the mast, which will be designed at a later date. Table 20 summarizes the important design parameters of the LHA(R) complement ship. At a full load displacement of 9,500 ltons, it is roughly the size of a cruiser.

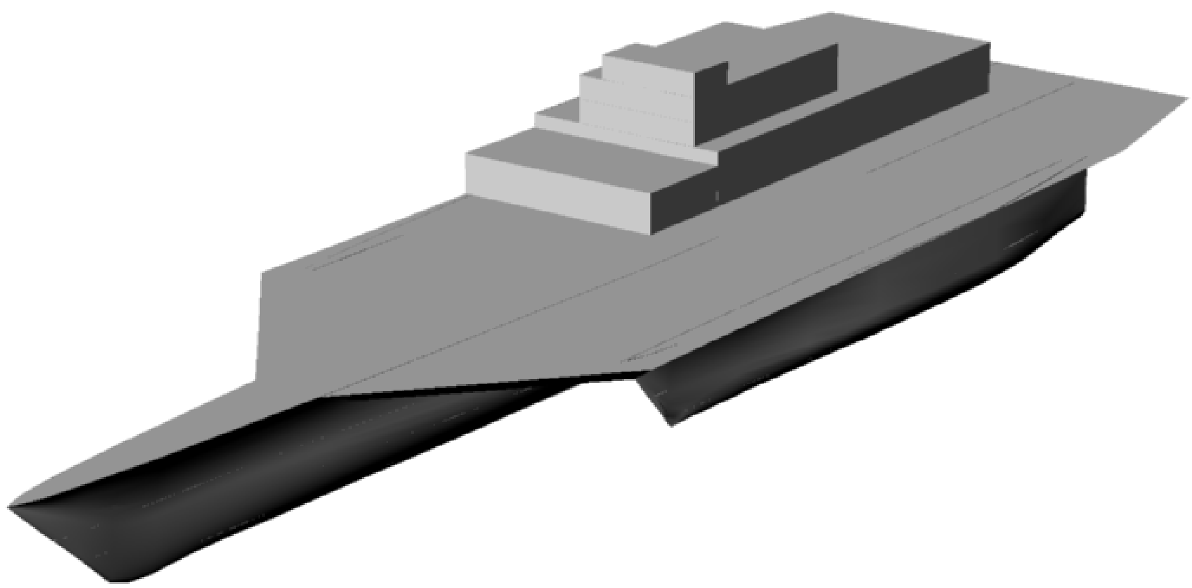

Figure 39: LHA(R) Complement Ship

Table 20: Design Summary

	Overall	Main Hull	Side Hull
Length (ft)	550	550	275
Beam (ft)	160	40	12
Draft (ft)	21		
Depth at Station 10 (ft)	40		
Aircraft	8 (6 MV-22 + 2 SH-60)		
Troops	200		
Cargo Volume (ft^3)	15,000		
Vehicle Parking Area (ft^2)	1,000		

5.2 Areas for Future Study

This study raised several issues involving trimaran design that were not fully investigated. To date, a considerable amount of work has been done on trimaran designs, but it has not been fully integrated, making the design process very difficult. Additionally, much of the information collected from model tests and other experiments is proprietary and not available for general use. Tools that are flexible enough to handle trimaran designs will simplify the design process tremendously. This will allow future designers to concentrate more on details and resolve many of the issues listed below.

There are several issues involving the resistance characteristics of the trimaran that must be resolved. These include the effect of wave interference between the hulls, as well as the effects of the side hull shape and location on the overall ship resistance. Computational models and model tests would both provide useful data on these issues.

The seakeeping characteristics of trimarans are only beginning to be understood. The RV Triton is currently undergoing tests that will help to determine how trimarans behave in various sea states. While the testing has not been completed, the results are encouraging [15]. The shape and placement of the side hulls could also have a significant effect on the seakeeping characteristics, so more experimental and computational tests will be required.

The design team did not attempt a detailed structural analysis of the cross-deck structure. This is a complex problem due to the joints between the hulls and the cross-deck, as well as the lack of knowledge of the bending moments that will be encountered. The loading conditions for a trimaran must be examined in depth, including the bending moments, flight deck loads, and blast material. Once the loading conditions are defined, the dimensions of the scantlings can be optimized. Finally, a detailed analysis of the cross-deck joints can be conducted. Studies have shown that composite materials may have several advantages in reducing the weight and cost of the ship [16]. There are numerous unanswered questions associated with the use of composite materials in warship design that must be investigated in more detail.

Finally, the deckhouse in this study was only designed to meet the area requirements. A great deal of work is required to determine the optimal mast design and integrate the combat systems of the ship.

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APPENDIX A

12/04/00

MISSION NEED STATEMENT FOR AMPHIBIOUS ASSAULT SHIP

Potential ACAT 1D

1. Defense Planning Guidance Element.

This Mission Need Statement (MNS) provides guideline requirements for an amphibious assault ship, which will replace retiring LHAs. This system/platform requirement is envisioned as a technological opportunity and responds to the following:

a. Defense Planning Guidance, FY 2001-2006
b. Joint Vision 2010
c. Joint Publication 3-02: Amphibious Warfare Doctrine
d. Navy Strategic Planning Guidance
e. Navy Operational Concepts: Forward…From the Sea
f. Marine Corps Warfighting Concepts:
  (1) Operational Maneuver from the Sea (OMFTS)
  (2) Ship to Objective Maneuver (STOM)
  (3) Marine Air-Ground Task Force Aviation and Operational Maneuver from the Sea (01/29/99)

2. Mission and Threat Analysis.

a. Mission. The amphibious assault ship must provide forward presence and power projection as an integral part of Joint, interagency and multinational maritime expeditionary forces. It must embark, support, and operate for sustained periods, in transit to and operations in an Amphibious Objective Area (AOA), with:

(1) Naval Amphibious tactical and administrative organizations for command, control, and operations;
(2) elements of a Landing Force (personnel, vehicles, assault amphibians, cargo, ammunition, and petroleum, oil and lubricants (POL));
(3) landing craft (Landing Craft, Air Cushion (LCAC) and conventional);
(4) aircraft (Short Takeoff Vertical Landing (STOVL) fixed-wing, rotary-wing, tiltrotor and Unmanned Aerial Vehicles (UAVs)).

The ship will launch preloaded assault craft (amphibian vehicles and landing craft), tiltrotors, helicopters, UAVs, and fixed-wing (STOVL) aircraft in support of amphibious operations. The amphibious assault ship must have the ability to serve as the primary command and control platform to conduct the primary mission of the Amphibious Task Force, and it must be capable of embarking with Joint, interagency and Combined command and control staff functions.

b. Objectives. The amphibious assault ship must be capable of supporting all aspects of the amphibious campaign, including the ability to respond to changing mission needs. It must be inherently flexible to support and conduct concurrent fixed-wing and rotary-wing/tiltrotor aircraft operations and simultaneous day and night well deck and flight deck operations. It must be capable of operating anywhere in the open ocean or littoral in a task force/group or independently commensurate with its self-defense capability over the full range of threat levels in peacetime, crisis, and warfighting scenarios. It must also be capable of operating in a highly dynamic physical environment, which may be very data-sparse, and must therefore be capable of collecting, assimilating, and applying multi-source environmental (meteorology and oceanography) data. Availability of forward land bases is not assumed. The amphibious assault ship must be interoperable with other Service, government agency and multinational forces. It must have the flexibility to be rapidly reconfigured to respond to changing threats and missions.

c. Capabilities. The core capabilities required for this ship to perform its mission include:

(1) Perform the following Naval Warfare mission areas: Amphibious Warfare (AMW), Command, Control and Communication (CCC), Information Warfare (IW), Intelligence (INT), Mobility (MOB), Fleet Support Operations (FSO), and Noncombatant Operations (NCO).
(2) Support the following Naval Warfare mission areas: Air Warfare (AW), Surface Warfare (SUW), Logistics (LOG), Naval Special Warfare (NCW), Strike Warfare (STW) (i.e., SAC Coordination, Area deconfliction, 3D air search radar, CSAR/TRAP) and Naval Surface Fire Support (NSFS) (i.e., SAC, Naval Fires Coordination), and Under-Sea Warfare (UW) (i.e., Nixie, Tactical System Control of UUVs, support of ASW Rotary Wing A/C).
(3)Support Marine Aviation functions: Offensive Air Support, Anti-Air Warfare, Assault Support, Air Reconnaissance, Electronic Warfare, Control of Aircraft and Missiles.
(4) Support for Organic Mine Warfare (MIW).
(5) Provide airspace and waterspace management throughout the Amphibious Objective Area (AOA).
(6) Provide medical assistance and force health protection in support of the following Naval Warfare mission areas: Amphibious Warfare (AMW), Fleet Support Operations (FSO), Missions of State (MOS), and Noncombatant Operations (NCO).
(7) Support I-level afloat aircraft and ship repair capability.

d. Threat and Threat Environment. The anticipated threat environment that this Amphibious Assault Ship is expected to operate in is described in 'Major Surface Ship Threat Assessment', ONI-TA-018-00, November 1999, and the DIA validated 'Landing Platform Dock (LPD 17) System Threat Assessment'(STAR), ONI-TA-036-00, January 2000.

e. Shortfalls of Existing Systems and Timing and Priority of Need. Existing LHA-1 Class ships will reach the end of their expected service lives between 2011 and 2015. Building more ships of this class or extending the service life is not operationally acceptable because:

(1) LHA class ships are not compatible with the future Aviation Combat Element (ACE) envisioned to be embarked.

(2) Their designs do not meet current environmental, habitability and survivability standards.
(3) The LHA design does not allow further growth in areas such as combat systems and topside weight.
(4) The LHA design does not adequately support evolving surface craft operations.

3. Nonmateriel Alternatives.

The large deck amphibious assault ship will remain critical to the successful conduct of amphibious operations despite any anticipated changes in the area of doctrine, operational concepts, organization, tactics, training, or leadership.,

4. Potential Materiel Alternatives.

Given the ship's flexibility, mobility, presence, and length of on-station time, as well as non-intrusive impact to host nations or allies (operating in international waters), no other platform provides a more cost-effective approach to supporting the mission. At this time, there are no known systems or programs deployed or in development or production by any of the other services or allied nations which address similar needs. A study of materiel alternatives should consider:

a. Modifications to the LHD class.
b. New Ship designs.

As part of their shipbuilding programs, various Allies have combat, hull, mechanical, and electrical stems programs ongoing or under development that offer possible cooperative opportunities. These subsystem designs will be examined. All meaningful cooperative opportunities can be realized without a formal cooperative development program for an amphibious assault ship.

5. Constraints.

a. Key Boundary Conditions.

(1) Design. The ship design must employ a total ship system architecture/engineering approach that optimizes life cycle cost and performance. Ship design should allow for advances in technology to be readily incorporated into the ship, provide for rapid ship reconfiguration to respond to mission changes, incorporate environmental safety and health planning throughout the life cycle to eliminate or mitigate pollution sources and health hazards, and incorporate optimized manning and maintenance concepts. Commercial standards, consistent with survivability and mission requirements, will be utilized for affordability. Navy standard equipment, existent logistics support systems, and commonality with other ship designs will be considered to minimize impact on infrastructure support requirements. The C4I systems shall be compatible with existing and planned C4I systems and equipment, comply with applicable information technology standards contained in the U.S. DOD Joint Technical Architecture (JTA),

and be functionally interoperable with other US, NATO, Coalition, Allied, and DOD component information systems. Capability to access standard intelligence, imagery, and geospatial information databases, products and services. The ship must be able to support Naval Amphibious tactical and administrative organizations for command, control, and operations, and elements of an embarked MAGTF including CE, ACE, CGE, and CSSE. The ship must be designed to support both the current and future aviation and surface assault assets including helicopters, MV-22, STOVL Joint Strike Fighters, UAVs, Advanced Amphibious Assault Vehicles, LCAC, and LCU.

(2) Personnel. Human Centered Design and Human Systems Integration will be used to optimize manpower requirements. The ship will be designed to accommodate varying ratios of male and female crew, embarked troops and staff. Front-end Manpower, Personnel and Training (MPT) analyses will be performed. Anticipated changes to Navy manpower requirements and infrastructure support are not expected, however, should any be identified, they will be documented and validated as part of the MPT analyses.

b. Operational Environments.

(1) The ship will be capable of conducting simultaneous well deck and flight deck operations day or night, throughout the widest possible range of weather and environmental conditions. The ship must be able to simultaneously conduct flight deck, well deck and UAV operations without conventional lighting by relying on completely Night Vision Device compatible lighting configurations and operating procedures. The ship will be designed to meet Level II survivability criteria specified in OPNAVINST 9070.1. The capability to continue to operate in a Chemical, Biological, and Radiological (CBR) environment is required.

(2) The ship must be able to operate in U.S., foreign and international waters in full compliance with existing U.S. and international pollution control laws and regulations.

(3) The ship C4I and weapons systems will be compatible in the operational electromagnetic environment.

(4) The ship C4I and weapons systems including any commercial or non-developed item (NDI) shall comply with applicable DOD, National, and International spectrum management policies and regulations.

6. Joint Potential Designator.

Joint Interest

APPENDIX B

ROC LIST

LHA(R) Required Operational Capabilities

ROC	Description	Comments
AAW 1	Provide air defense independently or in cooperation with other forces	Self defense
AAW 2	Provide air defense of a geographic area independently, or in cooperation with other forces	
AAW 4	Conduct air operations to support airborne anti-air operations	Support Marine AAW - launch, recover aircraft
AAW 6	Detect, identify, and track air targets	Maintain air plot, link with other ships
AAW 11	Repair own unit's AAW equipment	
AAW 12	Conduct casualty control procedures to maintain/restore own unit's AAW capabilities	
AMW 1	Load, transport and land combat equipment, material, supplies, and attendant personnel of a force or group in an amphibious assault	vehicles and equipment
AMW 2	Load, transport and land elements of a landing force with their equipment, material and supplies in an amphibious assault	people
AMW 3	Reembark and transport equipment, materials, supplies and personnel	
AMW 4	Serve as Primary Control Ship in ship-to-shore movement	
AMW 5	Conduct landing craft or amphibious vehicle operations to support an amphibious assault	
AMW 6	Conduct helicopter operations to support an amphibious assault	
AMW 7	Provide amphibious assault construction support for ship-to-shore operations and beach clearance	Ship-to-shore fuel systems
AMW 9	Conduct preassault cover and diversionary actions	
AMW 11	Conduct amphibious cargo handling operations	

AMW 12	Provide air control and coordination of air operations in the AOA	
AMW 14	Conduct NSFS against designated targets	Coordinate NSFS support against designated targets to support amphibious operations
AMW 15	Provide air operations to support amphibious operations	Fixed wing and rotary
AMW 17	Conduct VSTOL flight operations to support an amphibious assault	
AMW 20	Repair own unit's AMW equipment	
AMW 22	Protect/Evacuate (permissive or non-permissive) non-combatants, including transport to ATF or safe haven	
AMW 23	Conduct advance force operations for an amphibious assault	
AMW 24	Conduct direct action amphibious raids	
AMW 26	Conduct TRAP	
AMW 43	Conduct casualty control procedures to maintain/restore own unit's AMW capabilities	
ASU 1	Using antisurface armaments, engage surface threats	Self defense
ASU 2	Engage surface targets in cooperation with other forces	
ASU 4	Detect, identify, localize, and track surface ship targets	Radar, ESM
ASU 6	Disengage, evade and avoid surface attack	Countermeasures, EMCON
ASU 14	Repair own unit's ASU equipment	
ASU 17	Conduct casualty control procedures to maintain/restore own unit's ASU capabilities	
ASW 7	Attack submarines with antisubmarine armament	Guns
ASW 8	Disengage, evade, avoid, and deceive submarines	Countermeasures
ASW 9	Repair own unit's ASW equipment	
ASW 13	Conduct casualty control procedures to maintain/restore own unit's ASW capabilities	
CCC 1	Provide command and control facilities for a task organization commander/staff	Communications, Spaces

CCC 2	Coordinate and control the operations of the task organization or functional force to carry out assigned missions	Control helos, close air support aircraft
CCC 3	Provide own unit's command and control functions	
CCC 4	Maintain Navy Tactical Data System or data link capability	
CCC 6	Provide communications for own unit	
CCC 9	Relay communications	
CCC 19	Repair own unit's CCC equipment	
CCC 20	Conduct casualty control procedures to maintain/restore own unit's CCC capabilities	
CCC 21	Perform cooperative engagement	
C2W 1	Conduct EW support (ES) operations	
C2W 3	Conduct Electronic Protection (EP) operations	Detect jamming
C2W 5	Conduct coordinated C2W/IW operations with other forces in support of a JTF/group	
C2W 14	Repair own unit's C2W equipment	
C2W 16	Conduct casualty control procedures to maintain/restore own unit's C2W capabilities	
FSO 3	Provide support to other units	Support aircraft
FSO 6	Support/conduct SAR operations in a combat/noncombat environment	
FSO 9	Provide medical care to assigned and untasked personnel	
FSO 10	Provide first aid assistance	
FSO 11	Provide triage of casualties/patients	
FSO 12	Provide medical/surgical treatment for casualties/patients	
FSO 13	Provide medical, surgical, post-operative, and nursing care for casualties/patients	
FSO 14	Provide medical regulation, transport/evacuation, and receipt of casualties and patients	
FSO 16	Provide routine and emergency dental care	

INT 1	Support/Conduct intelligence collection	
INT 2	Provide intelligence	
INT 3	Conduct surveillance and reconnaissance	
INT 8	Process surveillance and reconnaissance information	
INT 9	Disseminate surveillance and reconnaissance information	
INT 15	Provide intelligence support for Non-Combatant Evacuation Operation (NEO)	
LOG 1	Conduct underway replenishment	
LOG 2	Transfer/Receive cargo and personnel	
LOG 3	Provide sealift for cargo and personnel	
LOG 6	Provide airlift of cargo and personnel	
LOG 9	Repair own unit's logistics equipment	
LOG 10	Conduct casualty control procedures to maintain/restore own unit's LOG capabilities	
MIW 3	Conduct mine neutralization/destruction	
MIW 6	Conduct magnetic silencing (degaussing, deperming, etc)	
MOB 1	Operate ship's propulsion plant to designed capability	Operate at ARG speed, machinery redundancy
MOB 2	Support/Provide safe, flyable aircraft for all-weather operations	
MOB 3	Prevent and control damage	
MOB 5	Maneuver in formation	
MOB 7	Perform seamanship, airmanship, and navigation tasks	
MOB 10	Replenish at sea	
MOB 12	Maintain the health and well-being of the crew	
MOB 17	Perform organizational level repairs to own unit's MOB equipment	
MOB 18	Conduct casualty control procedures to maintain/restore own unit's MOB capabilities	

APPENDIX C

HISTORICAL ANALYSIS OF OPERATIONS

ARG/MEU Crisis Response and Combat Actions since 1991					
(does not include Desert Storm/Desert Shield)					
Type of Operation	**Dates**	**Location**	**Operation**	**USN Units**	**USMC Units**
NEO/Embassy Security	Jan-91	Somalia	Eastern Exit	USS Guam (LPH 9) ARG	Unknown
				USS Trenton (LPD 14) ARG	Unknown
	Apr 94 - Aug 94	Rwanda/ Mombasa	Distant Runner	USS Peleliu (LHA 5) ARG	11th MEU
				USS Tripoli (LPH 10) ARG	15th MEU
	Mar 97 - Jun 97	Albania	Silver Wake	USS Nassau (LHA 4) ARG	26th MEU
	Apr 97 - May 97	Zaire	Guardian Retrieval	USS Nassau (LHA 4)	26th MEU elements
				USS Kearsarge (LHD 3)	22nd MEU elements
	Jun-97	West Africa	Noble Obelisk	USS Kearsarge (LHD 3)	22nd MEU elements
	Aug 90 - Jan 91	Liberia	Sharp Edge	USS Saipan (LHA 2)	26th MEU
	Apr 96 - Aug 96	Liberia	Assured Response	USS Guam (LPH 9)	22nd MEU elements
	May 96 - Aug 96	Central Africa	Quick Response	Unknown	Unknown
	Mar 97 - Jun 97	Albania	Silver Wake	USS Nassau (LHA 4) ARG	26th MEU
	Jun-98	Eritrea	Safe Departure	Unknown	11th MEU
Humanitarian Support	Dec-92	Somalia	Restore Hope	USS Tripoli (LPH 10) ARG	15th MEU
	Jul 93 - 1999	Balkans	Provide Promise	Unknown ARGs	Unknown MEUs, 26th MEU
	Jan 93 - Mar 94	Somalia	Sustain Hope	Unknown ARGs	I MEF elements
	Oct-93	Somalia		USS Guadalcanal (LPH 7) ARG	Unknown

	Apr 94 - Aug 94	Rwanda/ Mombasa	Support Hope	USS Peleliu (LHA 5) ARG	11th MEU
				USS Tripoli (LPH 10) ARG	15th MEU
	Aug-99	Turkey		USS Kearsarge (LHD 3) ARG	26th MEU
	Nov 91 - May 93	Cuba	GITMO	Unknown	Unknown
	May 94 0 Feb 96	Cuba	Sea Signal	Unknown	Unknown
	Jan 95 - Feb 95	Caribbean	Safe Passage	Unknown	Unknown
Sanctions Enforcement	Nov 93 - Aug 94	Haiti	Support Democracy	Unknown ARGs	Unknown
	Dec 98 - 2000	Arabian Gulf	Southern Watch	USS Peleliu (LHA 5) ARG	31st MEU
Deterrence	Oct-94	Arabian Gulf/Red Sea	Vigiliant Warrior	USS Tripoli (LPH 10) ARG	15th MEU
	Aug-95	Arabian Gulf	Vigilant Sentinel	USS New Orleans (LPH 11) ARG	I MEF elements
	Oct 97 - 2000	Arabian Gulf		USS Peleliu (LHA 5) ARG	13th MEU
				USS Guam (LPH 9)	24th MEU
	Feb-98	Arabian Gulf		USS Guam (LPH 9) ARG	Unknown
Withdrawal	Feb 95 - Mar 95	Somalia	United Shield	USS Belleau Wood (LHA 3) ARG	I MEF elements
				USS Essex (LHD 2) ARG	Unknown
TRAP	Jun-95	Bosnia		USS Kearsarge (LHD 3) ARG	24th MEU
Show of Force	Jun-98	Adriatic Sea	Determined Falcon	USS Wasp (LHD 1) ARG	26th MEU air elements
Peacekeeping	Sep-99	East Timor	Stabilise	USS Belleau Wood (LHA 3)	11th MEU
				USS Peleliu (LHA 5)	31st MEU
	Jun-99	Kosovo	Joint Guardian	USS Kearsarge (LHD 3) ARG	26th MEU
	Mar-99	Kosovo	Allied Force	USS Kearsarge (LHD 3) ARG	26th MEU
Strikes	Aug 95 - Sep 95	Bosnia	Deliberate Force	USS Kearsarge (LHD 3) ARG	Unknown
	Dec 98 - 2000	Arabian Gulf	Desert Fox	USS Belleau Wood (LHA 3) ARG	Unknown

Misc.	Jan 93 - Oct 94	Straits of Florida	Able Vigil	Unknown	Unknown
	Sep-94	Haiti	Restore Democracy	USS Wasp (LHD 1) ARG	Unknown

APPENDIX D

ADVANCED HULL FORM ROM MODEL

General Comments: This is a rough order of magnitude model, to give an estimate of the size, speed and range of a ship carrying a given payload. It only includes weight and powering calculations, and ignores volume, stability, and electrical powering.

Given: Amphibious Lift Capacity:
- # Aircraft
- Cargo Volume
- Vehicle Parking Area
- # Troops

STEP 1: Calculate Payload Weight (W_{PAY}) using equations from MathCad Model

Payload Weight includes:
- Aircraft Weight
- Aircraft Fuel Weight
- Cargo Weight
- Vehicle Weight
- Outfit and furnishings weight (Troops and Crew)
- Provisions Weight (Troops and Crew)
- Stores Weight (Troops and Crew)
- Fresh Water Weight (Troops and Crew)
- Crew and Effects Weight (Troops and Crew)
- Combat Systems Weight

Assumptions:
- Crew of 220
- Stores period of 30 days
- Combat Systems Weight 180 ltons
- For monohull, Outfit and Furnishing is not included with payload

STEP 2: Estimate Fuel Weight (W_{FUEL})

STEP 3: Calculate Deadweight (W_{DWT})

$$W_{DWT} = W_{PAY} + W_{FUEL}$$

STEP 4: Calculate Full Load Displacement (W_{FL})

Use Deadweight Fractions (F_{DWT}) for each hull type:

$$W_{FL} = W_{DWT}/F_{DWT}$$

Hull Type	F_{DWT}	Source	Hull Material
Monohull	0.23	Survey of existing ships	steel
Catamaran	0.42	Survey of existing ships	aluminum
Trimaran	0.42	Used F_{DWT} for catamaran	aluminum
SWATH	0.27	Survey of existing ships	aluminum
SES	0.27	Survey of existing ships	aluminum
Hydrofoil	0.22	Survey of existing ships	aluminum

Since the monohull deadweight fraction is for a steel ship, the displacement calculated above is used. For all other hull forms, an extra factor must be added to account for changing the hull to steel.

Changing from aluminum to steel doubles the structural weight of the ship. Using the structural weight fractions (F_S) from MAPC, the full load displacement is modified as follows:

$$W_{FL(actual)} = W_{FL} + F_S * W_{FL}$$

Structural Weight Fractions:	Catamaran	.28
	Trimaran	.3
	SWATH	.32
	SES	.28
	Hydrofoil	.27

STEP 5: Calculate Maximum Speed

Assuming SHP of 100,000 hp (same as DDG 51), determine SHP/ton. Use Speed-Power equations to solve for maximum speed. All curves are quadratic with form:

$$SHP/ton = a*V^2 + b*V + c$$

Hull Type	a	b	c	Source
Monohull	.0369	-.3026	-3.8949	Existing data
Catamaran	.0099	.0764	4.7081	MAPC
Trimaran	.0221	-.5187	4.9307	MAPC
SWATH	.0225	-.5313	5.9211	MAPC
SES	.016	.002	.001	MAPC
Hydrofoil	.0078	.3894	0	MAPC

STEP 6: Calculate Range

Using speed-power curve, assume endurance speed (V_e) of 20 kts and calculate SHP_e

$Range = W_{fuel}*V_e/(SHP_e*SFC)$

SFC assumed to be .3 lb/hp-hr.

Iterate fuel weight to get desired range.

Deadweight Fractions

	MAPC	Data							Used
		# Samples	Best Fit	R^2	Mean	Std Dev	Min	Max	
Monohull	x		0.23	0.84	0.22	0.09	0.05	0.48	0.23
Catamaran	0.38	4	0.42	0.94	0.4	0.21	0.22	0.68	0.42
Trimaran	0.5	x	x	x	x	x	x	x	0.42
SWATH	0.24	2	0.27	0.7	0.27	0.01	0.27	0.28	0.27
SES	0.28	6	0.29	0.95	0.29	0.1	0.14	0.4	0.29
Hydrofoil	0.37	12	0.24	0.97	0.26	0.04	0.22	0.32	0.22
SP Monohull	0.3	x	x	x	x	x	x	x	0.3

Trimaran

Assumptions:

Stores Period	30	days
SHP	100000	hp
SFC (endurance)	0.3	lb/hp-hr
Endurance Speec	20	kts
DWT Fraction	0.42	
W1 Fraction	0.3	

Speed-Power Coefficients: ax^2+bx+c

a =	0.0221	(from MAPC)
b =	-0.5187	
c =	4.9307	

Inputs:

Aircraft	**Number**	**Weight/ Aircraft (lton)**	**Total Weight (lton)**
MV-22	4	15.57	62.28
CH-53	2	14.83	29.66
CH-60	1	6.18	6.18
Totals	7		98.12

Cargo Volume: 52500 ft^3

Vehicle Parking Area: 1000 ft^2

Personnel	**Crew**	**Marines**
Officers	20	30
Enlisted	200	170
		200

Payload Weight Calculation

Amphibious Lift				**Crew**			
Aircraft	WF23	98.12	lton	Crew-related ou	WOFP	168.4	lton
Aircraft Fuel	WF42	420	lton	Crew Provisions	WF31	26.51786	lton
Cargo	WCARGO	1102.5	lton	Crew Stores	WF32	6.33468	lton
Vehicles	WV	64	lton	Crew Water	WF52	33	lton
Troop-related outl	WOFP	152.4	lton	Crew and Effect	WF10	24.82143	lton
Troop Provisions	WF31	24.10714	lton				
Troop Stores	WF32	5.7588	lton	**Combat Systems**		180	lton
Troop Water	WF52	30	lton				
Troops and Effect	WF10	23.44643	lton				
Total Payload Weight		2359.406	lton				

Full Load Displacement Calculation

Propulsion Fuel W	Wfuel	5300	lton	(iterate to meet range requirement)
Deadweight	WDWT	7659.406	lton	
Estimated Full Lo	WFLe	18236.68	lton	(this is for an aluminum hull)
Full Load	WFL	23707.69	lton	(this accounts for steel hull: W1 for steel is 2X W1 for Aluminum)

Speed Calculation

Power per Ton	SHP/WFL	4.218041	hp/lton
Max. Speed	V	22.00516	kts
		1.465429	kts

Range Calculation

Endurance SHP	SHPe	61944.54	hp	
Range	E	12777.02	nm	Iterate to get desired range

APPENDIX E

SUMMARY OF ARG VARIANTS

Variant	Size	A/C	LCAC	Cargo Volume (ft^3)	Vehicle Parking (ft^2)	Troops	L (ft)	B (ft)	Δ (Ltons)	Speed (knots)	Range (nm)
1	Large	17	2	180,000	25,000	800	710	90	22,341	26	12,212
	Small	14	1	10,000	45,000	2,200	700	100	22,135	24	9,668
2	Large	31	3	137,500	22,895	2,093	778	106	30,045	24	9,567
	Small	0	0	52,500	0	165	420	55	4,947	33	7,988
3	Large	31	2	180,000	25,000	2,093	778	106	30,045	24	9,482
	Small	0	1	10,000	9,000	670	530	70	7,872	27	9,585
4	Large	24	2	137,500	19,000	1,900	700	95	27,289	24	10,580
	Small	7	1	52,500	10,000	560	550	73	9,881	25	9,540
5	Large	24	1	180,000	25,000	800	710	96	23,290	26	11,853
	Small	7	2	10,000	75,000	800	710	96	23,290	26	12,104
6	Large	24	3	95,000	35,000	2,200	778	106	30,108	24	9,641
	Small	7	0	95,000	0	225	500	60	7,211	29	10,292
7	Large	17	3	137,500	25,000	800	700	90	22,145	26	12,436
	Small	14	0	52,500	7,500	800	700	80	14,826	31	16,807
8	Large	24	3	180,000	30,000	2,170	778	106	30,072	24	9,491
	Small	7	0	10,000	0	225	420	55	5,673	33	7,910
9	Large	31	1	137,500	30,000	1,400	850	100	27,924	27	11,638
	Small	0	2	52,500	15,000	800	585	85	18,580	26	14,564
10	Large	17	2	95,000	30,000	1,200	700	90	22,580	27	12,460
	Small	14	1	95,000	36,000	2,200	700	100	22,135	24	9,743
11	Large	17	1	137,500	30,000	1,200	700	90	22,145	27	12,460
	Small	14	2	52,500	50,000	800	700	90	22,145	26	13,858
12	Large	24	1	95,000	15,000	1,900	700	95	27,289	25	10,112
	Small	7	2	95,000	10,000	800	585	85	18,837	26	12,955
13	Large	24	2	137,500	19,000	1,900	700	95	27,289	24	10,580
	Small	7	1	52,500	9,000	670	530	75	9,369	26	9,402

14	Large	31	2	95,000	33,000	2,200	778	106	30,108	24	9,610
	Small	0	1	95,000	8,000	670	530	72	9,680	27	9,560
15	Large	24	2	137,500	19,000	1,900	700	95	27,289	24	10,580
	Small	7	1	52,500	5,000	180	500	75	8,246	26	9,573

APPENDIX F

SURVEY

1. Survey Development and Results

1.1 Survey Development

Our initial Overall Measure of Effectiveness (OMOE) model was created as described in Chapter 2 of the report. From this outline it was necessary to assign weightings to the different levels so that they would be representative. To accurately weight the parameters, we had to find a tool to measure the relative importance of one parameter to another. Although this input could have been obtained from the design team, this would have unfairly skewed the results and would have been poor engineering practice. Since the goal of this project is to design the optimal platform for the navy operator, a series of questions (a SURVEY) was created to obtain the relative importance of the weighted parameters from the operators. The Survey, revised several times, was composed of numerous pair-wise comparisons and several open-ended questions. These pair-wise comparisons allowed the operator to make numerical comparisons between two parameters on a linear scale. The questions provided valuable information regarding what the operator would like to see addressed or changed in the design of a new amphibious platform.

1.2 Survey Distribution

The survey was distributed to senior Navy and Marine Corps personnel with experience in Amphibious ship operations and requirements. Although more completed surveys were expected, a total of 10 surveys were returned. This number was deemed to be satisfactory at the beginning of survey. Some of the personnel surveyed are currently retired, but all are still working closely in support of the Navy and Marine Corps.

The survey was distributed via email and returned in the same manner.

2. Survey Results

2.1 Recording Results

The surveys were gathered and data collected from each of the pair-wise comparisons. Each of the comparisons had a scale ranging from 5 to 1 and back to 5, giving a total range of 9 possible selections. For numerical analysis, each block was given a number in order from 1 to 9 (where the left most 5 has value 1, followed by 4 having value of 2, etc). This is shown in the table below. Here a set of comparison results of 2 left, and 2 right would have numerical analysis values of 4 and 6, respectively, giving an average of 5 which corresponds back to a comparison value of 1, as expected.

Comparison Number	5	4	3	2	1	2	3	4	5
Numerical Analysis value	1	2	3	4	5	6	7	8	9

A spreadsheet was then created to record and process all of the survey results. Each result was read off and its corresponding numerical analysis value was entered into the spreadsheet. From this table, the mean and standard deviation were calculated for each question. From the mean numerical analysis value, a comparison number was determined for the results of each question. The results are shown in the following table:

		Numerical Analysis Result										Numerical	Comparison	
	Survey #	1	2	3	4	5	6	7	8	9	10	Average	Result	Direction
Amphibious Lift Capacity vs	Mobility	7	5	5	2	1	7	2	5	4	2	4.00	2.000	Left
	Selective Offload	4	5	4	3	5	7	5	7	5	4	4.90	1.100	Left
	Survivability	3	5	4	4	5	7	5	9	6	3	5.10	1.100	Right
	Mission Flexiblity	5	5	5	3	5	7	5	9	7	2	5.30	1.300	Right
1 MV-22 vs	1 LCAC	7	4	5	4	1	4	3	1	4	5	3.80	2.200	Left
	2 M1A1	5	4	4	3	1	1	3	1	4	3	2.90	3.100	Left
	4 cargo containers	6	5	4	4	1	6	3	1	4	5	3.90	2.100	Left
	75 Troops	6	5	4	1	5	5	3	5	4	3	4.10	1.900	Left
	Speed/Range	4	4	6	2	5	3	4	7	4	6	4.50	1.500	Left
	Seakeeping/Range	3	6	4	3	5	7	3	2	6	3	4.20	1.800	Left
	Stores/Speed	4	6	4	7	5	7	6	4	7	3	5.30	1.300	Right
	MV22/MH53	5	3	3	2	1	4	3	1	4	3	2.90	3.100	Left
	MV22/SH60	3	3	3	2	1	3	3	3	6	3	3.00	3.000	Left
	A/C spots/VLS	4	3	3	1	1	4	3	4	4	2	2.90	3.100	Left
	AMD/ability to surv	5	6	5	5	5	1	5	3	3	5	4.30	1.700	Left
	ASW/ability to surv	5	6	5	8	9	9	6	1	3	6	5.80	1.800	Right
	ASuW/ability to surv	5	6	5	1	5	1	6	5	3	6	4.30	1.700	Left
	small ship/large ship	4	6	6	8	5	1	6	5	6	3	5.00	1.000	Left
	small ship/1 LCAC	4	5	5	4	5	3	4	5	4	3	4.20	1.800	Left
	small ship/500 troops	5	6	6	4	8	2	4	5	4	3	4.70	1.300	Left
	small ship/3 JSF	4	6	7	8	8	4	5	5	4	3	5.40	1.400	Right
	Adding Stores/S.O.	5	4	4	7	5	9	4	9	6	6	5.90	1.900	Right

Since there was a significant quantity of measurements/questions taken, further analysis was performed to process the data and remove any dubious results. After a careful review of the statistical analysis tools available, the Chauvenet Criterion was employed. After applying the Chauvenet Criterion, several dubious points were identified and removed, a new mean was calculated, and a new comparison result obtained.

2.2 Chauvenet's Analysis

Suppose n measurements/observations of a quantity are taken. We shall assume that n is large enough that we may expect the results to follow a gaussian error distribution. This distribution may be used to compute the probability that a given reading will deviate a certain amount from the mean. We would not expect a probability much smaller than 1/n because this would be unlikely to occur in the set of n measurements. Thus, if the probability for the observed deviation of a certain point were less than 1/n, a suspicious eye would be cast at that point with an idea toward eliminating it from the data. Actually, a more restrictive test is usually applied to eliminate data points. It is known as the Chauvenet's criterion and specifies that a reading may be rejected if the probability of obtaining the particular deviation from the mean is less than 1/2n.

In applying Chauvenet's criterion to eliminate dubious data points, one first calculates the mean value and standard deviations of the individual points using all data points. The deviations of the individual points are then compared to the standard deviation and any dubious points are removed using the table shown below or direct application as shown below. For the final data presentation a new mean value and standard deviation are computed with the dubious points eliminated from the calculation. Note that Chauvenet's criterion might be applied a second and a third time to eliminate additional points; but this practice is unacceptable, and only the first application may be used.

$$1-P\left(\frac{d_i}{\sigma}\right) > \frac{1}{2n} \qquad 1-\frac{1}{2n} < P\left(\frac{d_i}{\sigma}\right) = 2(X) \qquad X = \frac{1-\frac{1}{2n}}{2} = \frac{1}{2} - \frac{1}{n}$$

Where X is the value read from the table for the gaussian error function, which is entered using indices of $\eta = \frac{d_i}{\sigma}$,

Example (1):

For n=10, X=.4750

We then look in a table for the gaussian error function, and see that

For X=.4750, we have $\eta = \frac{d_i}{\sigma} = 1.96$

Example (2):

For n=9, X=.47222

We then look in a table for the gaussian error function, and find we have to interpolate:

For X=.47193, we have $\eta = \frac{d_i}{\sigma} = 1.91$

For X=.47257, we have $\eta = \frac{d_i}{\sigma} = 1.92$

Interpolating, we get that for X=.47222, that $\eta = \frac{d_i}{\sigma} = 1.91453$

Chauvenet's criterion for rejecting a reading

Number of readings, n	Ratio of maximum acceptable deviation to standard deviation, d_{max}/σ
3	1.38
4	1.54
5	1.65
6	1.73
7	1.80
10	1.96
15	2.13
25	2.33
50	2.57
100	2.81
300	3.14
500	3.29
1,000	3.48

Reference: Holman, J.P., Experimental Methods for Engineers (5th edition).

Gaussian Error Function Table

2.3 Final Results

The final results are shown in a table below, with the dubious points removed (seen by the blanks in the columns). A histogram was also created to graphically show the difference in the pre-Chauvenet and post-Chauvenet analysis. This histogram is shown following the table.

The pre (before) and post (after) processing refers to the application of Chauvenet's Criterion. Pre-processing (before) is before Chauvenet is applied, while Post-processing (after) is after Chauvenet is applied.

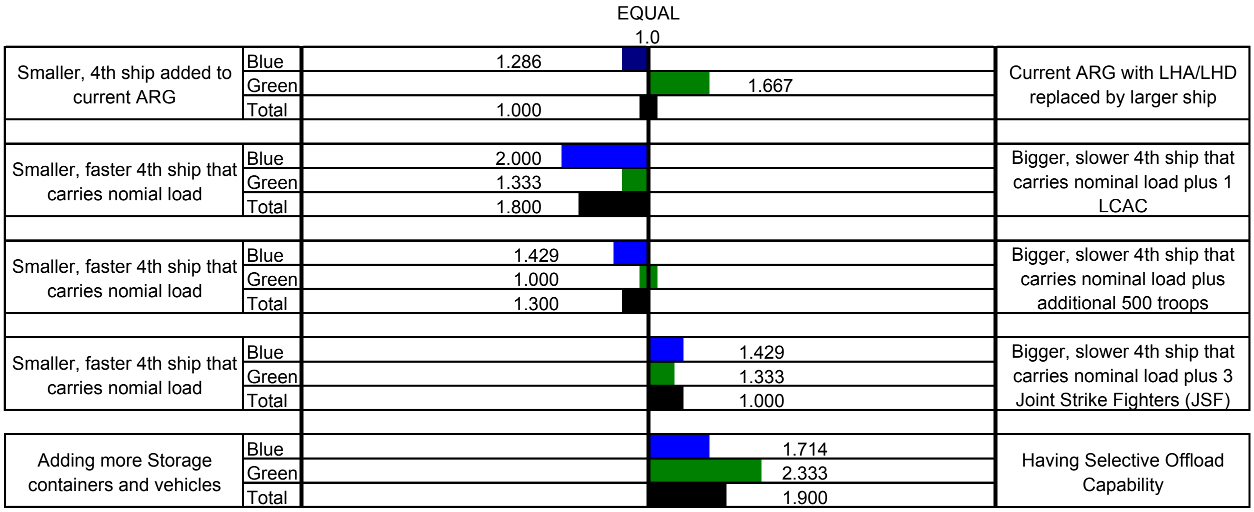
The results are also broken down into responses from both the Navy and Marines, designated as Blue and Green, respectively. Out of the ten (10) respondents to the survey, seven (7) were Navy, while only three (3) were Marines. These results also follow.

		Numerical Analysis Result										Numerical	Comparison	
	Survey #	1	2	3	4	5	6	7	8	9	10	Average	Result	Direction
Amphibious Lift Capacity vs	Mobility	7	5	5	2	1	7	2	5	4	2	4.00	2.000	Left
	Selective Offload	4	5	4	3	5	7	5	7	5	4	4.90	1.100	Left
	Survivability	3	5	4	4	5	7	5		6	3	4.67	1.333	Left
	Mission Flexiblity	5	5	5	3	5	7	5	9	7	2	5.30	1.300	Right
1 MV-22 vs	1 LCAC	7	4	5	4	1	4	3	1	4	5	3.80	2.200	Left
	2 M1A1	5	4	4	3	1	1	3	1	4	3	2.90	3.100	Left
	4 cargo containers	6	5	4	4	1	6	3	1	4	5	3.90	2.100	Left
	75 Troops	6	5	4		5	5	3	5	4	3	4.44	1.556	Left
	Speed/Range	4	4	6	2	5	3	4	7	4	6	4.50	1.500	Left
	Seakeeping/Range	3	6	4	3	5	7	3	2	6	3	4.20	1.800	Left
	Stores/Speed	4	6	4	7	5	7	6	4	7	3	5.30	1.300	Right
	MV22/MH53	5	3	3	2	1	4	3	1	4	3	2.90	3.100	Left
	MV22/SH60	3	3	3	2	1	3	3	3		3	2.67	3.333	Left
	A/C spots/VLS	4	3	3	1	1	4	3	4	4	2	2.90	3.100	Left
	AMD/ability to surv	5	6	5	5	5		5	3	3	5	4.67	1.333	Left
	ASW/ability to surv	5	6	5	8	9	9	6		3	6	6.33	2.333	Right
	ASuW/ability to surv	5	6	5	1	5	1	6	5	3	6	4.30	1.700	Left
	small ship/large ship	4	6	6	8	5		6	5	6	3	5.44	1.444	Right
	small ship/1 LCAC	4	5	5	4	5	3	4	5	4	3	4.20	1.800	Left
	small ship/500 troops	5	6	6	4		2	4	5	4	3	4.33	1.667	Left
	small ship/3 JSF	4	6	7	8	8	4	5	5	4	3	5.40	1.400	Right
	Adding Stores/S.O.	5	4	4	7	5	9	4	9	6	6	5.90	1.900	Right

		5.0	EQUAL 1.0	5.0	
Amphibious Lift Capacity	Before	2.000			Mobility
	After	2.000			
Amphibious Lift Capacity	Before	1.100			Selective Offload Capability
	After	1.100			
Amphibious Lift Capacity	Before			1.100	Survivability
	After	1.333			
Amphibious Lift Capacity	Before			1.300	Mission Flexiblity
	After			1.300	
Adding 1 MV22	Before	2.200			Adding 1 LCAC
	After	2.200			
Adding 1 MV22	Before	3.100			Adding 2 M1A1 tanks
	After	3.100			
Adding 1 MV22	Before	2.100			Adding 4 Cargo Containers
	After	2.100			
Adding 1 MV22	Before	1.900			Adding 75 Troops
	After	1.556			
Increasing Speed	Before	1.500			Range
	After	1.500			
Being able to perform flight/well deck operations in higher sea states	Before	1.800			Range
	After	1.800			
Carrying extra 2 weeks worth of stores	Before			1.300	Speed
	After			1.300	
2 MV22	Before	3.100			2 MH53
	After	3.100			
2 MV22	Before	3.000			2 SH60 with dipping sonar (ASW)
	After	3.333			
Maintain current # of flight deck/hanger bay aircraft	Before	3.100			Add VLS in place of 2 MV22 spots
	After	3.100			

		5.0	EQUAL 1.0	5.0
Improved missile defense system	Before	1.700		Increased ability to survive a missile salvo
	After	1.333		
Improved ASW system	Before		1.800	Increased ability to survive a torpedo attack
	After		2.333	
Improved ASuW system	Before	1.700		Increased ability to survive attack by small boats
	After	1.700		
Smaller, 4th ship added to current ARG	Before		1.000	Current ARG with LHA/LHD replaced by larger ship
	After		1.444	
Smaller, faster 4th ship that carries nomial load	Before	1.800		Bigger, slower 4th ship that carries nominal load plus 1 LCAC
	After	1.800		
Smaller, faster 4th ship that carries nomial load	Before	1.300		Bigger, slower 4th ship that carries nominal load plus additional 500 troops
	After	1.667		
Smaller, faster 4th ship that carries nomial load	Before		1.400	Bigger, slower 4th ship that carries nominal load plus 3 Joint Strike Fighters (JSF)
	After		1.400	
Adding more Storage containers and vehicles	Before		1.900	Having Selective Offload Capability
	After		1.900	

		5.0	EQUAL 1.0	5.0
Amphibious Lift Capacity	Blue	2.286		Mobility
	Green	1.333		
	Total	2.000		
Amphibious Lift Capacity	Blue	1.286		Selective Offload Capability
	Green		1.333	
	Total	1.100		
Amphibious Lift Capacity	Blue	1.429		Survivability
	Green		2.333	
	Total		1.100	
Amphibious Lift Capacity	Blue	1.429		Mission Flexiblity
	Green		3.000	
	Total		1.300	
Adding 1 MV22	Blue	2.000		Adding 1 LCAC
	Green	2.667		
	Total	2.200		
Adding 1 MV22	Blue	3.143		Adding 2 M1A1 tanks
	Green	3.000		
	Total	3.100		
Adding 1 MV22	Blue	1.714		Adding 4 Cargo Containers
	Green	3.000		
	Total	2.100		
Adding 1 MV22	Blue	2.000		Adding 75 Troops
	Green	1.667		
	Total	1.900		
Increasing Speed	Blue	2.000		Range
	Green		1.667	
	Total	1.500		
Being able to perform flight/well deck operations in higher sea states	Blue	1.714		Range
	Green	2.000		
	Total	1.800		
Carrying extra 2 weeks worth of stores	Blue		1.429	Speed
	Green		1.000	
	Total		1.300	
2 MV22	Blue	3.000		2 MH53
	Green	3.333		
	Total	3.100		
2 MV22	Blue	3.429		2 SH60 with dipping sonar (ASW)
	Green	2.000		
	Total	3.000		
Maintain current # of flight deck/hanger bay aircraft spots	Blue	3.429		Add VLS in place of 2 MV22 spots
	Green	2.333		
	Total	3.100		
Improved missile defense system	Blue	1.429		Increased ability to survive a missile salvo
	Green	2.333		
	Total	1.700		
Improved ASW system	Blue		3.000	Increased ability to survive a torpedo attack
	Green	3.000		
	Total		1.800	


EQUAL
1.0
Smaller, 4th ship added to current ARG
Blue 1.286
Green 1.667
Total 1.000
Current ARG with LHA/LHD replaced by larger ship
Smaller, faster 4th ship that carries nomial load
Blue 2.000
Green 1.333
Total 1.800
Bigger, slower 4th ship that carries nominal load plus 1 LCAC
Smaller, faster 4th ship that carries nomial load
Blue 1.429
Green 1.000
Total 1.300
Bigger, slower 4th ship that carries nominal load plus additional 500 troops
Smaller, faster 4th ship that carries nomial load
Blue 1.429
Green 1.333
Total 1.000
Bigger, slower 4th ship that carries nominal load plus 3 Joint Strike Fighters (JSF)
Adding more Storage containers and vehicles
Blue 1.714
Green 2.333
Total 1.900
Having Selective Offload Capability

This survey is in support of an academic research project at MIT. This project is a group effort of three naval officers in the MIT 13A Program (Naval Architecture and Marine Construction) : LT Rob Bebermeyer, USN; LT Shelly Price, USN; LT Kostas Galanis, HN. Any questions or problems with the survey should be directed to LT Rob Bebermeyer at 617-253-7938, or

The purpose of this survey is to obtain relative weightings for various parameters in a study of the requirements for LHA replacement alternatives. The assignment of numerical values (such as 1 knot of speed, 75 troops, etc.) is done only for the purpose of making a realistic comparison, and does not in any way imply that these values would be the final design

Upon completion of this survey, please return to:

LT Robert Bebermeyer
Navy Academic Office, MIT, RM 5-309
77 Massachusetts Ave
Cambridge, MA 02139

or email back (if completed on the computer)

rbeberme@mit.edu

The survey is composed of 4 parts. See the bottom tabs for the worksheets: Pair-wise 1, Pair-wise 2, Pair-wise 3, & Questions.

Your time and effort in completing and returning survey is greatly appreciated.

Your Contact Information:
Name:
Organization:
Email:

This questionnaire asks you to conduct pairwise comparisons of the parameters listed below.
The results of this survey will be used to determine the relative importance of the various parameters.

Make comparisons in the following manner:

In order to effectively accomplish the mission of the ARG, "**Amphibious Lift Capacity**" **is more (or less) important than "Mobility"**. Check the number that you think most appropriately fills the blank.

A value of 1 indicates that the two are equal in importance. Any other value weights the importance of one to the other.

1. Overall Analysis (I)

	Amphibious lift capacity more important ←					→ Other Parameter more important				
	5	4	3	2	1	2	3	4	5	
Amphibious Lift Capacity										Mobility
Amphibious Lift Capacity										Selective Offload Capability
Amphibious Lift Capacity										Survivability
Amphibious Lift Capacity										Mission Flexibility

Keyword	Definition
Amphibious Lift Capacity	# of Troops, Aircraft, Landing Craft, Cargo Space, Vehicle Space available to conduct Marine Missions
Mobility	Speed, Seakeeping Ability, Endurance Range, Amount of Stores
Selective Offload Capability	Ability to offload desired equipment when required without pulling into port (Sea Basing Enabler)
Survivability	Includes self defense, passive features and countermeasures
Mission Flexibility	Ability to perform split ARG operations and respond to emergent situations

This part of the questionnaire asks you to conduct pairwise comparisons of the parameters listed below.

Make comparisons as before

A value of 1 indicates that the two are equal in importance. Any other value weights the importance of one to the other.

1. Amphibious Lift Capacity

	5	4	3	2	1	2	3	4	5	
Adding 1 MV-22										Adding 1 LCAC
Adding 1 MV-22										Adding 2 M1A1 tanks
Adding 1 MV-22										Adding 4 cargo containers
Adding 1 MV-22										Adding 75 troops

2. Mobility

	5	4	3	2	1	2	3	4	5	
Increasing Speed										Increasing Range
Being able to peform flight/well deck operations in higher sea states										Increasing speed by 5 knots
Carrying extra 2 weeks worth of stores										Increasing speed by 5 knots

3. Mission Performance

	5	4	3	2	1	2	3	4	5	
2 MV-22										2 MH-53
2 MV-22										2 SH-60 with dipping sonar (ASW)
Maintain current # of flight deck/hanger bay aircraft spots										Add VLS in place of 2 MV-22 spots

4. Survivability

	5	4	3	2	1	2	3	4	5	
Improved missile defense system										Increased ability to survive a missile salvo
Improved ASW defense system										Increased ability to survive a torpedo attack
Improve ASUW defense system										Increased ability to survive attack by small boats

NEW ARG CONCEPTS:
The LHA can be replaced by several options, including:

(1) A larger version of the LHD, capable of carrying either the current or future ACE (with JSF and MV-22) Design is similar in size to a CV.

(2) Several options that would consist of two ships replacing the current LHA. This would therefore add a 4th ship to the ARG.

NOMINAL CONCEPT LOAD for 4th Ship: 2 MV-22, 500 Troops

Make comparisons as before.

A value of 1 indicates that the two are equal in importance. Any other value weights the importance of one to the other.

1. Ship Variants

	5	4	3	2	1	2	3	4	5	
Smaller, faster 4th ship added to current ARG										Current ARG with LHA/LHD replaced by larger ship
Smaller, faster 4th ship that carries nominal load										Bigger, slower 4th ship that carries nominal load plus 1 LCAC
Smaller, faster 4th ship that carries nominal load										Bigger, slower 4th ship that carries nominal load plus additional 500 troops
Smaller, faster 4th ship that carries nominal load										Bigger, slower 4th ship that carries nominal load plus 3 Joint Strike Fighters (JSF)
Adding more Storage Containers and Vehicles										Having Selective Offload Capability

Q1 If you could increase or add three(3) capabilities to the current ARG, what would they be in order of preference?

Q2 What missions would you assign to a smaller, faster 4th ship added to the current ARG?

Q3 What do you see as the two most significant obstacles to Selective Offloading in the ARG?

Q4 Is there anything else you would like to add or comment on? Any and all information would be greatly appreciated.

APPENDIX G

SUMMARY OF PLATFORM VARIANTS

Monohull

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1626.9	1050	2676.9	11638.7	27.3	5001	0.606
2	---+	1	10000	0	200	792	525	1317	5725.9	33.4	5082	0.596
3	+--+	7	10000	0	200	1234.5	800	2034.5	8845.7	29.4	5013	0.679
4	+-++	7	10000	1000	200	1298.5	850	2148.5	9341.3	29	5044	0.709
5	--++	1	10000	1000	200	856	560	1416	6156.3	32.7	5042	0.625
6	++--	7	52500	0	100	2005.4	1300	3305.4	14371.5	25.8	5014	0.663
7	++-+	7	52500	0	200	2127	1400	3527	15334.8	25.4	5061	0.725
8	-+++	1	52500	1000	200	1748.5	1150	2898.5	12602	26.7	5058	0.667
9	-+-+	1	52500	0	200	1684.5	1100	2784.5	12106.3	27	5037	0.637
10	00a0	4	31250	0	150	1404.1	925	2329.1	10126.5	28.4	5063	0.627
11	000A	4	31250	500	200	1496.9	975	2471.9	10747.5	27.9	5029	0.673
12	000a	4	31250	500	100	1375.3	900	2275.3	9892.8	28.5	5043	0.611
13	-+--	1	52500	0	100	1562.9	1025	2587.9	11251.7	27.6	5050	0.575
14	+-+-	7	10000	1000	100	1176.9	775	1951.9	8486.7	29.8	5062	0.648
15	a000	1	31250	500	150	1209.4	800	2009.4	8736.5	29.5	5076	0.599
16	A000	7	31250	500	150	1651.9	1075	2726.9	11856.2	27.2	5026	0.686
17	----	1	10000	0	100	670.4	440	1110.4	4827.8	35.1	5052	0.536
18	0	4	31250	500	150	1436.1	950	2386.1	10374.3	28.2	5076	0.642
19	0a00	4	10000	500	150	989.8	650	1639.8	7129.8	31.3	5054	0.621
20	--+-	1	10000	1000	100	734.4	475	1209.4	5258.2	34.2	5007	0.565
21	++++	7	52500	1000	200	2191	1450	3641	15830.5	25.2	5077	0.755
22	0A00	4	52500	500	150	1882.3	1225	3107.3	13510.2	26.3	5026	0.665
23	00A0	4	31250	1000	150	1468.1	950	2418.1	10513.5	28.1	5009	0.657
24	+++-	7	52500	1000	100	2069.4	1350	3419.4	14867.1	25.6	5033	0.693
25	+---	7	10000	0	100	1112.9	725	1837.9	7991	30.3	5029	0.618

Catamaran

(using MAPC speed-power curve)

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1795.3	1100	2895.3	8823.7	22.3	2337	x
2	---+	1	10000	0	200	960.4	1950	2910.4	8869.7	22.2	4122	0.572
3	+--+	7	10000	0	200	1402.9	1500	2902.9	8847	22.2	3179	0.659
4	+-++	7	10000	1000	200	1466.9	1450	2916.9	8889.6	22.1	3058	0.69
5	--++	1	10000	1000	200	1024.4	1900	2924.4	8912.3	22.1	3997	0.602
6	++--	7	52500	0	100	2173.8	750	2923.8	8910.7	22.1	1578	x
7	++-+	7	52500	0	200	2295.4	600	2895.4	8824.1	22.3	1275	x
8	-+++	1	52500	1000	200	1916.9	1000	2916.9	8889.5	22.1	2109	x
9	-+-+	1	52500	0	200	1852.9	1050	2902.9	8846.8	22.2	2225	x
10	00a0	4	31250	0	150	1572.5	1350	2922.5	8906.7	22.1	2842	0.608
11	000A	4	31250	500	200	1665.3	1250	2915.3	8884.8	22.1	2638	0.654
12	000a	4	31250	500	100	1543.7	1375	2918.7	8895.2	22.1	2898	0.592
13	-+--	1	52500	0	100	1731.3	1200	2931.3	8933.5	22	2518	0.556
14	+-+-	7	10000	1000	100	1345.3	1550	2895.3	8823.9	22.3	3293	0.628
15	a000	1	31250	500	150	1377.8	1550	2927.8	8922.8	22.1	3257	0.579
16	A000	7	31250	500	150	1820.3	1100	2920.3	8900.1	22.1	2317	x
17	----	1	10000	0	100	838.8	2075	2913.8	8880.1	22.2	4381	0.51
18	0	4	31250	500	150	1604.5	1325	2929.5	8928	22	2782	0.623
19	0a00	4	10000	500	150	1158.2	1750	2908.2	8863.2	22.2	3702	0.6
20	--+-	1	10000	1000	100	902.8	2025	2927.8	8922.8	22.1	4255	0.54
21	++++	7	52500	1000	200	2359.4	550	2909.4	8866.8	22.2	1163	x
22	0A00	4	52500	500	150	2050.7	875	2925.7	8916.6	22.1	1840	x
23	00A0	4	31250	1000	150	1636.5	1275	2911.5	8873.1	22.2	2694	0.639
24	+++-	7	52500	1000	100	2237.8	675	2912.8	8877.2	22.2	1426	x
25	+---	7	10000	0	100	1281.3	1650	2931.3	8933.6	22	3463	0.597

Trimaran

(using MAPC speed-power curve, DWT fraction .42)

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1795.3	675	2470.3	7646.1	34.2	5046	0.619
2	---+	1	10000	0	200	960.4	360	1320.4	4086.8	43.7	5035	0.615
3	+--+	7	10000	0	200	1402.9	525	1927.9	5967.3	37.7	5028	0.694
4	+-++	7	10000	1000	200	1466.9	550	2016.9	6242.8	37	5035	0.724
5	--++	1	10000	1000	200	1024.4	385	1409.4	4362.3	42.6	5044	0.644
6	++--	7	52500	0	100	2173.8	825	2998.8	9282.1	31.8	5080	0.674
7	++-+	7	52500	0	200	2295.4	875	3170.4	9813.2	31.1	5096	0.735
8	-+++	1	52500	1000	200	1916.9	725	2641.9	8177.2	33.4	5067	0.68
9	-+-+	1	52500	0	200	1852.9	700	2552.9	7901.7	33.8	5063	0.65
10	00a0	4	31250	0	150	1572.5	590	2162.6	6693.4	36	5038	0.641
11	000A	4	31250	500	200	1665.3	625	2290.3	7089.1	35.2	5039	0.686
12	000a	4	31250	500	100	1543.7	575	2118.7	6558	36.3	5011	0.626
13	-+--	1	52500	0	100	1731.3	650	2381.3	7370.7	34.7	5040	0.589
14	+-+-	7	10000	1000	100	1345.3	500	1845.3	5711.8	38.3	5003	0.664
15	a000	1	31250	500	150	1377.8	520	1897.8	5874.1	37.9	5059	0.615
16	A000	7	31250	500	150	1820.3	680	2500.3	7739.1	34.1	5022	0.698
17	----	1	10000	0	100	838.8	315	1153.8	3571.3	46.1	5041	0.555
18	0	4	31250	500	150	1604.5	600	2204.5	6823.4	35.8	5026	0.656
19	0a00	4	10000	500	150	1158.2	440	1598.2	4947	40.5	5083	0.639
20	--+-	1	10000	1000	100	902.8	340	1242.8	3846.7	44.8	5052	0.586
21	++++	7	52500	1000	200	2370.3	890	3249.4	10057.7	30.8	5057	0.766
22	0A00	4	52500	500	150	2050.7	775	2825.7	8746.4	32.5	5064	0.677
23	00A0	4	31250	1000	150	1636.5	610	2246.5	6953.4	35.5	5014	0.671
24	+++-	7	52500	1000	100	2237.8	850	3087.8	9557.6	31.4	5083	0.704
25	+---	7	10000	0	100	1281.3	480	1761.3	5451.8	39	5032	0.634

Hydrofoil

(using MAPC speed-power curve)

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1795.3	x	x	x	x	x	x
2	---+	1	10000	0	200	960.4	440	1400.4	8083.9	22	946	
3	+--+	7	10000	0	200	1402.9	x	x	x	x	x	x
4	+-++	7	10000	1000	200	1466.9	x	x	x	x	x	x
5	--++	1	10000	1000	200	1024.4	375	1399.4	8078.1	22.1	807	
6	++--	7	52500	0	100	2173.8	x	x	x	x	x	x
7	++-+	7	52500	0	200	2295.4	x	x	x	x	x	x
8	-+++	1	52500	1000	200	1916.9	x	x	x	x	x	x
9	-+-+	1	52500	0	200	1852.9	x	x	x	x	x	x
10	00a0	4	31250	0	150	1572.5	x	x	x	x	x	x
11	000A	4	31250	500	200	1665.3	x	x	x	x	x	x
12	000a	4	31250	500	100	1553.7	x	x	x	x	x	x
13	-+--	1	52500	0	100	1731.3	x	x	x	x	x	x
14	+-+-	7	10000	1000	100	1345.3	50	1395.3	8054.9	22.1	108	
15	a000	1	31250	500	150	1377.8	20	1397.8	8069	22.1	43	
16	A000	7	31250	500	150	1820.3	x	x	x	x	x	x
17	----	1	10000	0	100	838.8	560	1398.8	8074.8	22.1	1206	
18	0	4	31250	500	150	1604.5	x	x	x	x	x	x
19	0a00	4	10000	500	150	1158.2	240	1398.2	8071.7	22.1	517	
20	--+-	1	10000	1000	100	902.8	500	1402.8	8097.9	22	1074	
21	++++	7	52500	1000	200	2359.4	x	x	x	x	x	x
22	0A00	4	52500	500	150	2050.7	x	x	x	x	x	x
23	00A0	4	31250	1000	150	1636.5	x	x	x	x	x	x
24	+++-	7	52500	1000	100	2237.8	x	x	x	x	x	x
25	+---	7	10000	0	100	1281.3	120	1401.3	8089.6	22	258	

SWATH (using MAPC speed-power curve)

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1795.3	2100	3895.3	19043.6	22.3	5061	0.597
2	---+	1	10000	0	200	960.4	1100	2060.4	10072.9	29.6	5012	0.588
3	+--+	7	10000	0	200	1402.9	1600	3002.9	14680.9	25.2	5002	0.671
4	+-++	7	10000	1000	200	1466.9	1700	3166.9	15482.7	24.6	5039	0.701
5	--++	1	10000	1000	200	1024.4	1200	2224.4	10874.6	28.7	5064	0.618
6	++--	7	52500	0	100	2173.8	1800	3973.8	19427.7	22.1	4252	0.653
7	++-+	7	52500	0	200	2295.4	1675	3970.4	19410.9	22.1	3960	0.715
8	-+++	1	52500	1000	200	1916.9	2075	3991.9	19515.7	22	4880	0.658
9	-+-+	1	52500	0	200	1852.9	2125	3977.9	19447.3	22	5015	0.627
10	00a0	4	31250	0	150	1572.5	1800	3372.5	16487.8	23.9	5010	0.618
11	000A	4	31250	500	200	1665.3	1900	3565.3	17430.4	23.3	5003	0.664
12	000a	4	31250	500	100	1543.7	1800	3343.7	16347.2	24	5053	0.603
13	-+--	1	52500	0	100	1731.3	1975	3706.3	18119.6	22.8	5002	0.566
14	+-+-	7	10000	1000	100	1345.3	1550	2895.3	14155	25.6	5026	0.64
15	a000	1	31250	500	150	1377.8	1600	2977.8	14558.1	25.3	5044	0.591
16	A000	7	31250	500	150	1820.3	2100	3920.3	19166.1	22.2	5029	0.676
17	----	1	10000	0	100	838.8	975	1813.8	8867.4	31.2	5046	0.529
18	0	4	31250	500	150	1604.5	1850	3454.5	16888.7	23.6	5028	0.633
19	0a00	4	10000	500	150	1158.2	1350	2508.2	12262.5	27.3	5053	0.614
20	--+-	1	10000	1000	100	902.8	1050	1952.8	9547	30.3	5048	0.558
21	++++	7	52500	1000	200	2359.4	1625	3984.4	19479.3	22	3829	0.745
22	0A00	4	52500	500	150	2050.7	1925	3975.7	19437	22	4545	0.655
23	00A0	4	31250	1000	150	1636.5	1900	3536.5	17289.5	23.4	5043	0.649
24	+++-	7	52500	1000	100	2237.8	1750	3987.8	19496.1	22	4120	0.684
25	+---	7	10000	0	100	1281.3	1475	2756.3	13475.4	26.2	5024	0.61

SES (using MAPC speed-power curve)

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1795.3	1100	2895.3	12779.2	22.1	2555	0.588
2	---+	1	10000	0	200	960.4	1925	2885.4	12735.4	22.1	4486	0.573
3	+--+	7	10000	0	200	1402.9	1500	2902.9	12812.8	22	3474	0.66
4	+-++	7	10000	1000	200	1466.9	1425	2891.9	12764.3	22.1	3313	0.691
5	--++	1	10000	1000	200	1024.4	1875	2899.4	12797.2	22	4348	0.603
6	++--	7	52500	0	100	2173.8	725	2898.8	12794.9	22	1682	x
7	++-+	7	52500	0	200	2295.4	600	2895.4	12779.7	22.1	1393	x
8	-+++	1	52500	1000	200	1916.9	975	2891.9	12764.1	22.1	2267	x
9	-+-+	1	52500	0	200	1852.9	1050	2902.9	12812.6	22	2432	x
10	00a0	4	31250	0	150	1511.7	1375	2886.7	12741.5	22.1	3203	0.609
11	000A	4	31250	500	200	1665.3	1225	2890.3	12757.3	22.1	2850	0.655
12	000a	4	31250	500	100	1543.7	1350	2893.7	12772.4	22.1	3137	0.593
13	-+--	1	52500	0	100	1731.3	1175	2906.3	12827.8	22	2718	0.557
14	+-+-	7	10000	1000	100	1345.3	1550	2895.3	12779.4	22.1	3599	0.629
15	a000	1	31250	500	150	1377.8	1525	2902.8	12812.3	22	3532	0.58
16	A000	7	31250	500	150	1820.3	1075	2895.3	12779.4	22.1	2496	0.668
17	----	1	10000	0	100	838.8	2050	2888.8	12750.5	22.1	4771	0.511
18	0	4	31250	500	150	1604.5	1300	2904.5	12819.9	22	3009	0.624
19	0a00	4	10000	500	150	1158.2	1750	2908.2	12836.4	22	4046	0.601
20	--+-	1	10000	1000	100	902.8	2000	2902.8	12812.3	22	4633	0.541
21	++++	7	52500	1000	200	2359.4	525	2884.4	12731.2	22.1	1224	x
22	0A00	4	52500	500	150	2050.7	850	2900.7	12803.3	22	1970	x
23	00A0	4	31250	1000	150	1636.5	1250	2886.5	12740.4	22.1	2912	0.639
24	+++-	7	52500	1000	100	2237.8	650	2887.8	12746.3	22.1	1513	x
25	+---	7	10000	0	100	1281.3	1625	2906.3	12828	22	3759	0.598

Semi-Planing Monohull (speed-power curve from MAPC data, DWT fraction .3)

	Pattern	# Aircraft	Cargo Volume (ft^3)	VP Area (ft^2)	Troops	Payload Weight (lton)	Fuel Weight (lton)	Deadweight (lton)	Displacement (lton)	Speed (kts)	Range (nm)	OMOE
1	-++-	1	52500	1000	100	1795.3	1400	3195.3	12994.2	23.5	5002	0.599
2	---+	1	10000	0	200	960.4	750	1710.4	6955.4	28.4	5006	0.586
3	+--+	7	10000	0	200	1402.9	1100	2502.9	10178.5	25.2	5018	0.671
4	+-++	7	10000	1000	200	1466.9	1150	2616.9	10642.1	24.9	5017	0.702
5	--++	1	10000	1000	200	1024.4	800	1824.4	7419	27.8	5006	0.616
6	++--	7	52500	0	100	2173.8	1700	3873.8	15753.6	22.4	5010	0.656
7	++-+	7	52500	0	200	2295.4	1800	4095.4	16654.7	22.1	5018	0.718
8	-+++	1	52500	1000	200	1916.9	1500	3416.9	13895.2	23.1	5012	0.661
9	-+-+	1	52500	0	200	1852.9	1450	3302.9	13431.6	23.3	5012	0.63
10	00a0	4	31250	0	150	1572.5	1250	2822.5	11478.2	24.4	5056	0.619
11	000A	4	31250	500	200	1665.3	1300	2965.3	12059	24	5005	0.665
12	000a	4	31250	500	100	1543.7	1225	2768.7	11259.6	24.5	5051	0.605
13	-+--	1	52500	0	100	1731.3	1350	3081.3	12530.6	23.8	5002	0.568
14	+-+-	7	10000	1000	100	1345.3	1050	2395.3	9741	25.5	5005	0.64
15	a000	1	31250	500	150	1377.8	1100	2477.8	10076.3	25.3	5068	0.591
16	A000	7	31250	500	150	1820.3	1450	3270.3	13299.4	23.4	5062	0.679
17	----	1	10000	0	100	838.8	675	1513.8	6156.1	29.5	5091	0.526
18	0	4	31250	500	150	1604.5	1250	2854.5	11608.3	24.3	5000	0.635
19	0a00	4	10000	500	150	1158.2	925	2083.2	8471.9	26.7	5069	0.613
20	--+-	1	10000	1000	100	902.8	725	1627.8	6619.7	28.8	5085	0.556
21	++++	7	52500	1000	200	2359.4	1750	4109.4	16711.6	22	4862	0.72
22	0A00	4	52500	500	150	2050.7	1600	3650.7	14846.4	22.7	5004	0.658
23	00A0	4	31250	1000	150	1636.5	1300	2936.5	11941.8	24.1	5054	0.65
24	+++-	7	52500	1000	100	2238	1750	3987.8	16217.2	22.2	5010	0.687
25	+---	7	10000	0	100	1281.3	1000	2281.3	9277.4	25.9	5004	0.61

APPENDIX H

SHCP INPUT FILES

Tri.dat

```
0001KOST   - 13.414    TRIMARAN     01/27/99   NPU      30.0     0.25    0.30
C
C
C  Lt Konstantinos Galanis HN
C  APR 10, 2002
C  Trimaran LHA
C  Resizing the sidehulls to meet stability requirements
C          Feasibility Analysis
C
C
HULL     :test18.scp
DESIGN   :DESIGN.DAT
HYDRO    :HYDRO.DAT
COMP     :comp.dat
INTACT   :INTACT.DAT
FLOODL   :floodl.dat
DAMTS    :DAMTS.dat
TRIML    :TRIML.DAT
DAMXC    :damxc.dat
stop
```

USER NOTES
C -- identifier for the outer skin of the sidehulls
B -- identifier for the inner skin of the sidehulls
TRIML -- used to calculate trim lines with various compartments flooded, works okay
floods shell to shell, including appendages
DAMXC -- used to calc damaged RA curves -- not sure how it works

Design.dat

```
9999999999999999999     20.00      0.0
9999
```

Hydro.dat

```
46  0  0  7  2  1
     1.00      2.00      3.00      4.00      5.00      5.50      6.00
     6.50      7.00      7.50      8.00      8.50      9.00      9.50
    10.00     10.50     11.00     11.50     12.00     12.50     13.00
    13.50     14.00     14.50     15.00     16.00     16.50     17.00
```

```
    17.50     18.00     18.50     19.00     19.50     20.00     20.50
    21.00     21.50     22.00     22.50     23.00     23.50     24.00
    24.50     25.00     25.50     26.00
 28
     0.00      7.00     14.00     21.00     31.50     42.00     52.50
    63.00     84.00    105.00    126.00    147.00    168.00    189.00
   210.00    231.00    252.00    265.00    273.00    294.00    315.00
   336.00    357.00    380.00    450.00    490.00    520.00    550.00
```

Comp.dat

```
100 FUEL TANK STBD side   +1 .95-9999999999999B999999C999999 999999 999999
 101 STBD AMMA - 001      +1 .95-999999 245.50B999999C999999 999999 999999
 102 STBD AMMA - 002      +1 .95 245.50 268.00B999999C999999 999999 999999
 103 STBD AMMA - 003      +1 .95 268.00 284.00B999999C999999 999999 999999
 104 STBD AMMA - 004      +1 .95 284.00 304.00B999999C999999 999999 999999
 105 STBD AMMA - 005      +1 .95 304.00 320.00B999999C999999 999999 999999
 106 STBD AMMA - 006      +1 .95 320.00 335.00B999999C999999 999999 999999
 107 STBD AMMA - 007      +1 .95 335.00 348.00B999999C999999 999999 999999
 108 STBD AMMA - 008      +1 .95 348.009999999B999999C999999 999999 999999
 109 STBD AMMA - all     +1 .95-9999999999999B999999C999999 999999 999999
 201 PORT AMMA - 001      -1 .95-999999 245.50B999999C999999 999999 999999
 202 PORT AMMA - 002      -1 .95 245.50 268.00B999999C999999 999999 999999
 203 PORT AMMA - 003      -1 .95 268.00 284.00B999999C999999 999999 999999
 204 PORT AMMA - 004      -1 .95 284.00 304.00B999999C999999 999999 999999
 205 PORT AMMA - 005      -1 .95 304.00 320.00B999999C999999 999999 999999
 206 PORT AMMA - 006      -1 .95 320.00 335.00B999999C999999 999999 999999
 207 PORT AMMA - 007      -1 .95 335.00 348.00B999999C999999 999999 999999
 208 PORT AMMA - 008      -1 .95 348.009999999B999999C999999 999999 999999
 209 PORT AMMA - all      -1 .95-9999999999999B999999C999999 999999 999999
 011 main hull compt   1    0 .95-999999  23.50 999999 999999 999999 999999
 012 main hull compt   2    0 .95 23.50   94.50 999999 999999 999999 999999
 013 main hull compt   3    0 .95 94.59  126.40 999999 999999 999999 999999
 014 main hull compt   4    0 .95 126.40 152.70 999999 999999 999999 999999
 015 main hull compt   5    0 .95 152.70 211.60 999999 999999 999999 999999
 016 main hull compt   6    0 .95 211.60 253.80 999999 999999 999999 999999
 017 main hull compt   7    0 .95 253.89 291.40 999999 999999 999999 999999
 018 main hull compt   8    0 .95 291.40 338.40 999999 999999 999999 999999
 019 main hull compt   9    0 .95 338.40 376.00 999999 999999 999999 999999
 020 main hull compt  10    0 .95 376.00 408.00 999999 999999 999999 999999
 021 main hull compt  11    0 .95 408.00 437.00 999999 999999 999999 999999
 022 main hull compt  12    0 .95 437.00 480.00 999999 999999 999999 999999
 010 MAIN HULL CPTS 1-3     0 .95-999999 121.00 999999 999999 999999 999999
 009 MAIN HULL CPTS 2-4     0 .95  77.00 165.00 999999 999999 999999 999999
 008 MAIN HULL CPTS 3-5     0 .95 121.00 199.98 999999 999999 999999 999999
 007 MAIN HULL CPTS 4-6     0 .95 165.00 231.00 999999 999999 999999 999999
```

```
 006 MAIN HULL CPTS 5-7     0 .95 199.98 291.50 999999 999999 999999 999999
 005 MAIN HULL CPTS 6-8     0 .95 211.60 338.40 999999 999999 999999 999999
 004 MAIN HULL CPTS 7-9     0 .95 291.50 374.00 999999 999999 999999 999999
 003 MAIN HULL CPTS 8-10    0 .95 335.50 434.50 999999 999999 999999 999999
 002 MAIN HULL CPTS 9-11    0 .95 374.00 474.98 999999 999999 999999 999999
 001 MAIN HULL CPTS10-12    0 .95 434.50 517.00 999999 999999 999999 999999
END
```

Intact.dat

```
3 0      8522      9467     10414
  1 1       0.0       0.0       0.0                                   1
          20.0      20.0      20.0
 20      0.0    5.0   10.0   15.0   20.0   25.0   30.0   35.0   40.0   45.0
        50.0   55.0   60.0   65.0   70.0   75.0   80.0   85.0   90.0   95.0
END
```

Damts.dat

```
1       20.40
 20    -15.0  -10.0  -5.0   0.0   5.0   10.0   15.0   20.0   25.0   30.0
 20     35.0   40.0  45.0  50.0   55.0  60.0   65.0   70.0   75.0   80.0
C side hull damaged
  103  104  018  019
END
```

Damxc.dat

```
1       20.00
  1       00.00
         20.00
 10      0.0    5.0   10.0   15.0   20.0   25.0   30.0   35.0   40.0   45.0
  001  002  003  004  005  006  007  008  009  010
END
```

Floodl.dat

```
0.00     36.00
     63.00     36.00       1.0
9999999999
  500      0.80      0.85      0.90      0.95                            1  1
       12         3
     27.50     77.00    121.00    165.00    199.98    231.00    291.50    335.50
    374.00    434.50    474.98    517.00
```

Triml.dat

```
1   -22.000    27.500      0.95
  2    27.500   110.000      0.95
  3   110.000   137.500      0.95
  4   137.500   165.000      0.95
  5   165.000   220.000      0.95
  6   220.000   275.000      0.95
  7   275.000   302.500      0.95
  8   302.500   357.500      0.95
  9   357.500   412.000      0.95
 10   412.000   467.500      0.95
 11   467.500   495.000      0.95
 12   495.000   550.000      0.95
999
   1   2    3
   2   3    4
   3   4    5
   4   5    6
   5   6    7
   6   7    8
   7   8    9
   8   9   10
   9  10   11
  10  11   12
99999
```

APPENDIX I

STRUCTURAL ANALYSIS

FWD PART:

```
""
VERSION 8.0.22
$JOB INFORMATION
EVALUATION 0 1
$STRUCTURE PARAMETERS
2 2 1 3 ,,, 1 1 ,
REFERENCE 0 0 0 6096
UNITS N mm kg kg 0.001 1.0259e-006 9806.64 "$"
CRITERIA default 1.5 1.25
$MATERIAL PROPERTY
 STEEL_1  1 .204E+06 0.30 .351E+03 .351E+03 .351E+03 .780E-05 .780E-05
0.00 1.00
NOBALANCE float PROCEED NOADJUST NOCLOSE
$ SUBSTRUCTURE IDENTIFIER
SUBS 1
0  0  0  0  0  0
$ MODULE IDENTIFIER==>/top/main/fwd1
MODULE   1  -6705.6  0  0  0  0  0
BOUNDARY     1    1   1  1
RESTRAINT    1    1   1  5 110000
+            1    1   1  9 010000
END
CASE 1 "SAGGING WAVE + SAGGING MOMENT"
Y  1.0  GS
IMMERSION   0   0   0
0    30    0
LINPRESS     0.01226    6
LINPRESS     0.01226    7
LINPRESS     0.01226    8
LINPRESS     0.01226    9
LINPRESS     0.01226    26
LINPRESS     0.01226    27
LINPRESS     0.01226    28
LINPRESS     0.01226    29
LINPRESS     0.01226    30
LINPRESS     0.005271   10
LINPRESS     0.005271   11
LINPRESS     0.005271   12
LINPRESS     0.005271   13
LINPRESS     0.005271   14
LINPRESS     0.005271   15
LINPRESS     0.005271   16
LINPRESS     0.005271   17
LINPRESS     0.005271   18
LINPRESS     0.005271   19
LINPRESS     0.005271   20
DPRESS       0.02       2
DPRESS       0.02       3
DPRESS       0.02       4
3.2E+10    3.2E+10   0.0      0.0
```

endloads

MEDIUM PART

```
""
VERSION 8.0.22
$JOB INFORMATION
EVALUATION 0 1
$STRUCTURE PARAMETERS
2 2 1 3 ,,, 1 1 ,
REFERENCE 0 0 0 6096
UNITS N mm kg kg 0.001 1.0259e-006 9806.64 "$"
CRITERIA default 1.5 1.25
$MATERIAL PROPERTY
 STEEL_1  1 .204E+06 0.30 .351E+03 .351E+03 .351E+03 .780E-05 .780E-05
0.00 1.00
NOBALANCE float PROCEED NOADJUST NOCLOSE
$ SUBSTRUCTURE IDENTIFIER
SUBS 1
0  0  0  0  0  0
$ MODULE IDENTIFIER==>/top/main/mid1
MODULE   1  50292  0  0  0  0  0
BOUNDARY     1    1   1  1
RESTRAINT    1    1   1  0 110000
+            1    1   1  8 010000
END
CASE 1 "SAGGING WAVE + SAGGING MOMENT"
Y  1.0  GS
IMMERSION   0   0   0
0    30    0
LINPRESS     0.01226    17
LINPRESS     0.01226    18
LINPRESS     0.01226    19
LINPRESS     0.01226    20
LINPRESS     0.01226    21
LINPRESS     0.01226    22
LINPRESS     0.01226    23
LINPRESS     0.01226    24
LINPRESS     0.01226    25
LINPRESS     0.01226    26
LINPRESS     0.01226    27
LINPRESS     0.01226    28
LINPRESS     0.01226    29
LINPRESS     0.01226    30
LINPRESS     0.01226    31
LINPRESS     0.01226    32
LINPRESS     0.005271   6
LINPRESS     0.005271   7
LINPRESS     0.005271   8
LINPRESS     0.005271   9
LINPRESS     0.005271   10
LINPRESS     0.005271   11
LINPRESS     0.005271   12
LINPRESS     0.005271   13
LINPRESS     0.005271   14
LINPRESS     0.005271   15
```

```
LINPRESS     0.005271   16
DPRESS       0.02       2
DPRESS       0.02       3
DPRESS       0.02       4
3.2E+10    3.2E+10   0.0      0.0
endloads
```

AFT PART

```
""
VERSION 8.0.22
$JOB INFORMATION
EVALUATION 0 1
$STRUCTURE PARAMETERS
2 2 1 3 ,,, 1 1 ,
REFERENCE 0 0 0 6096
UNITS N mm kg kg 0.001 1.0259e-006 9806.64 "$"
CRITERIA default 1.5 1.25
$MATERIAL PROPERTY
 STEEL_1  1 .204E+06 0.30 .351E+03 .351E+03 .351E+03 .780E-05 .780E-05
0.00 1.00
NOBALANCE float PROCEED NOADJUST NOCLOSE
$ SUBSTRUCTURE IDENTIFIER
SUBS 1
0  0  0  0  0  0
$ MODULE IDENTIFIER==>/top/main/aft1
MODULE   1  117348  0  0  0  0  0
BOUNDARY     1    1   1  1
RESTRAINT    1    1   1  0 110000
+            1    1   1  6 010000
END
CASE 1 "SAGGING WAVE + SAGGING MOMENT"
Y  1.0  GS
IMMERSION   0   0   0
0    30    0
LINPRESS     0.01226    6
LINPRESS     0.01226    7
LINPRESS     0.01226    8
LINPRESS     0.01226    9
LINPRESS     0.01226    21
LINPRESS     0.01226    22
LINPRESS     0.01226    23
LINPRESS     0.01226    24
LINPRESS     0.01226    25
LINPRESS     0.01226    26
LINPRESS     0.01226    27
LINPRESS     0.01226    28
LINPRESS     0.01226    29
LINPRESS     0.01226    30
LINPRESS     0.01226    31
LINPRESS     0.01226    32
LINPRESS     0.005271   10
LINPRESS     0.005271   11
LINPRESS     0.005271   12
LINPRESS     0.005271   13
LINPRESS     0.005271   14
```

```
LINPRESS     0.005271   15
LINPRESS     0.005271   16
LINPRESS     0.005271   17
LINPRESS     0.005271   18
LINPRESS     0.005271   19
LINPRESS     0.005271   20
DPRESS       0.02       2
DPRESS       0.02       3
DPRESS       0.02       4
3.2E+10    3.2E+10   0.0       0.0
endloads
```